Chapter 15: Geology and Soils

15.1 INTRODUCTION

This chapter of the Environmental Impact Statement (EIS) describes the topography, geology, and soils in the study area, and presents the analysis the Federal Railroad Administration (FRA) and the New Jersey Transit Corporation (NJ TRANSIT) conducted of the potential environmental effects of the Preferred Alternative on these resources. The discussion of topography refers to issues related to elevation and slopes, while geology refers to both bedrock geology and geology of unconsolidated surficial deposits (including soils and sediments). The evaluation in this chapter considers these resources relative to their physical characteristics and geotechnical capability to accommodate the tunnels, structures, embankments, and other elements of the Preferred Alternative and describes how the Preferred Alternative addresses those conditions. The Port Authority of New York and New Jersey (PANYNJ), in its role as Project Sponsor, has accepted and relied on the evaluations and conclusions of this chapter.

This chapter reflects the following changes made since the Draft EIS (DEIS) for the Hudson Tunnel Project:

- The chapter incorporates design modifications related to the permanent features of the Project (e.g., modifications to surface tracks and tunnel alignment) and changes to construction methods and staging.
- The chapter is updated to describe current conditions in the affected environment and additional information related to geologic faults in the New Jersey portion of the study area is now included.
- Additional information is now included on how the Preferred Alternative would protect the cliff face of the Palisades and what construction methods the Project Sponsor would use to manage risk related to geologic faults in the New Jersey waterfront area.

This chapter contains the following sections:

15.2 ANALYSIS METHODOLOGY

During development of this Environmental Impact Statement (EIS), FRA and NJ TRANSIT developed methodologies for evaluating the potential effects of the Hudson Tunnel Project in coordination with the Project's Cooperating and Participating Agencies (i.e., agencies with a permitting or review role for the Project). The methodologies used for analysis of soils and geology are summarized in this chapter.

Following completion of the Draft Environmental Impact Statement (DEIS), the PANYNJ became the Project Sponsor for the Hudson Tunnel Project (see Chapter 1, "Purpose and Need," Section 1.1.2, for more information). Consistent with the roles and responsibilities defined in Section 1.1.1 of that chapter, as the current Project Sponsor, the PANYNJ will comply with mitigation measures and commitments identified in the Record of Decision (ROD).

15.2.1 ANALYSIS TECHNIQUES

FRA and NJ TRANSIT consulted the following published literature and other data sources to gather information regarding soils and geology for the study area, including seismic data:

- United States Geological Survey (USGS) 7.5-Minute Topographic Map;
- USGS National Seismic Hazard Map of New York;
- State of New Jersey Geographical Information System (GIS) Database;
- New Jersey Department of Environmental Protection (NJDEP), New Jersey Geological and Water Survey guidance and maps;
- USGS maps for northern New Jersey and southern New York region (bedrock and surficial geologic maps);
- *Bedrock Geologic Map of the New Jersey Portions of the Weehawken and Central Park Quadrangles, Bergen, Hudson and Passaic Counties, New Jersey* (Draft Version) by Donald H. Monteverde and Francesca Rea;
- Hudson River Estuary Data and Maps;
- United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS); and
- Soil Survey Geographic (SSURGO) Database.

15.2.2 STUDY AREA

The study area for the geological evaluation is the area within 500 feet on either side of the Project site; a larger area was examined to assess available data regarding the distribution and characteristics of major sediment and rock units in and around the study area. Potential impacts to or from geological resources have been evaluated with respect to the available data regarding the following geologic conditions:

- Asbestos-containing rock: Serpentinite is a naturally-occurring asbestos-containing rock known to be present along portions of the Hudson River shoreline in Hoboken and Manhattan and may be encountered within the Project area. Serpentinite contains chrysotile (asbestos) and other asbestiform[1] fibers/minerals, which can present a health hazard when the fibers are inhaled. Naturally occurring asbestos (NOA) occurs in rocks and soil as a result of natural geological processes. Natural weathering and human activities may disturb NOA-bearing rock or soil and release mineral fibers into the air.

- Steep slopes and landslides: Steep slopes are geologic hazards because of the susceptibility of generating landslides. Landslide activity is most common during the winter and spring months during freeze-thaw cycles, which expand bedrock fractures and debris on steep slopes.
- Liquefaction: Soil liquefaction occurs when a saturated soil loses cohesive strength, causing it to flow like a liquid. It can occur when a stress is applied, such as excavation and/or drilling for construction. During studies for the Access to the Region's Core (ARC) Project, both the soils west of the Palisades and those adjacent to and underlying the Hudson River were studied by the ARC Project's seismic experts with respect to liquefaction potential. Although some of these soils are soft, the liquefaction potential was determined not to be a significant concern for that project.[2]
- Bedrock faults and seismic activity: Such large-scale land displacements could affect construction activities and although investigated and not anticipated to represent a significant hazard for the Project, the Project is located in a moderate seismic zone and accordingly is being designed in accordance with appropriate seismic design criteria[3].

15.3 AFFECTED ENVIRONMENT: EXISTING CONDITIONS

The analysis of existing conditions in the study area for the Preferred Alternative is divided into three sections: the New Jersey section; the Hudson River section; and the New York section. **Figure 15-1** depicts bedrock geology. Known geologic hazards in the Project area, including fault lines, are depicted in **Figure 15-2**, based on available published data from the USGS. (Refer to Figures 2-5 and 2-6, in Chapter 2, "Project Alternatives and Description of the Preferred Alternative," for profiles and elevations of the new tunnel in the study area, showing generally where soils and bedrock are expected along the new tunnel alignment for the Preferred Alternative.) Amtrak has conducted preliminary geotechnical borings and will continue to update the information about the existing geology of the entire Project alignment as the design advances, using data from the ongoing geotechnical boring program.

The study area is situated within the Hudson River Valley. The topography is dominated by the Palisades sill (or ridge), which would host the western tunnel alignment and portal. The ground surface elevation of the Preferred Alternative area ranges from almost 300 feet above sea level on top of the Palisades sill to about 50 feet below sea level within the Hudson River channel.

15.3.1 NEW JERSEY

15.3.1.1 BEDROCK GEOLOGY

In New Jersey, the study area lies within the Piedmont physiographic province. This area is a broad lowland interrupted by long, northeast-trending ridges and uplands. The Palisades are the most prominent physiographic feature in the eastern part of the province, as a prominent

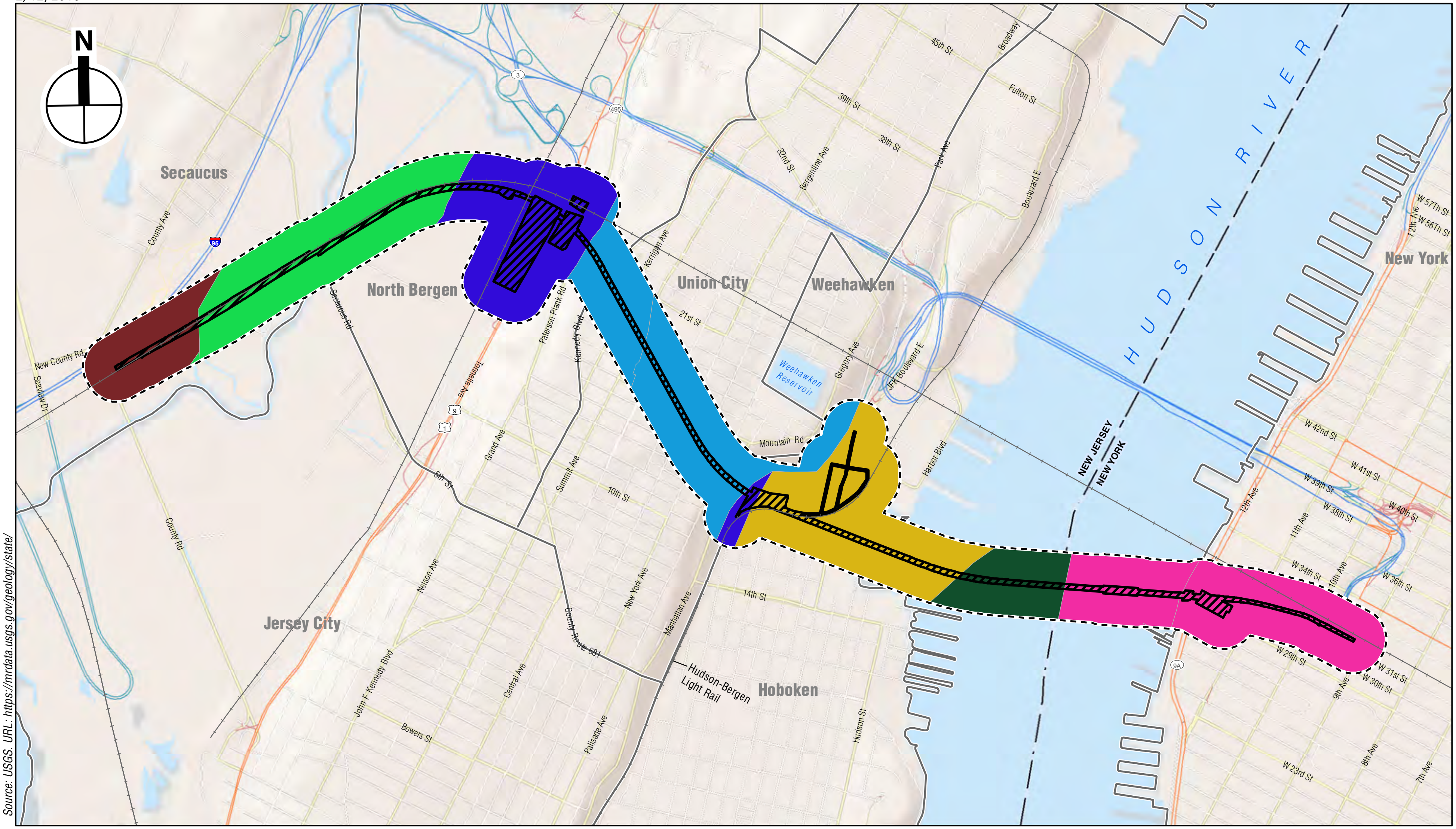
---

1 Asbestiform describes a mineral, like asbestos, that has a fibrous form.

2 Federal Transit Administration and NJ TRANSIT, *Access to the Region's Core Final Environmental Impact Statement* (FEIS), October 2008, Chapter 4.11, incorporated herein by reference, and provided in **Appendix 15** of this EIS.

3 Amtrak. Hudson Tunnel Project Design Criteria Manual (Revision 4, 2019).

2/12/2018



Source: USGS. URL: https://mrdata.usgs.gov/geology/state/

- Project Site
- Municipal Boundaries
- Study Area (500-Foot Boundary)
- Passaic Formation Mudstone facies
- Lockatong Formation Arkosic Sandstone facies
- Lockatong Formation
- Diabase
- Stockton Formation
- Manhattan Schist
- Manhattan Formation, undivided

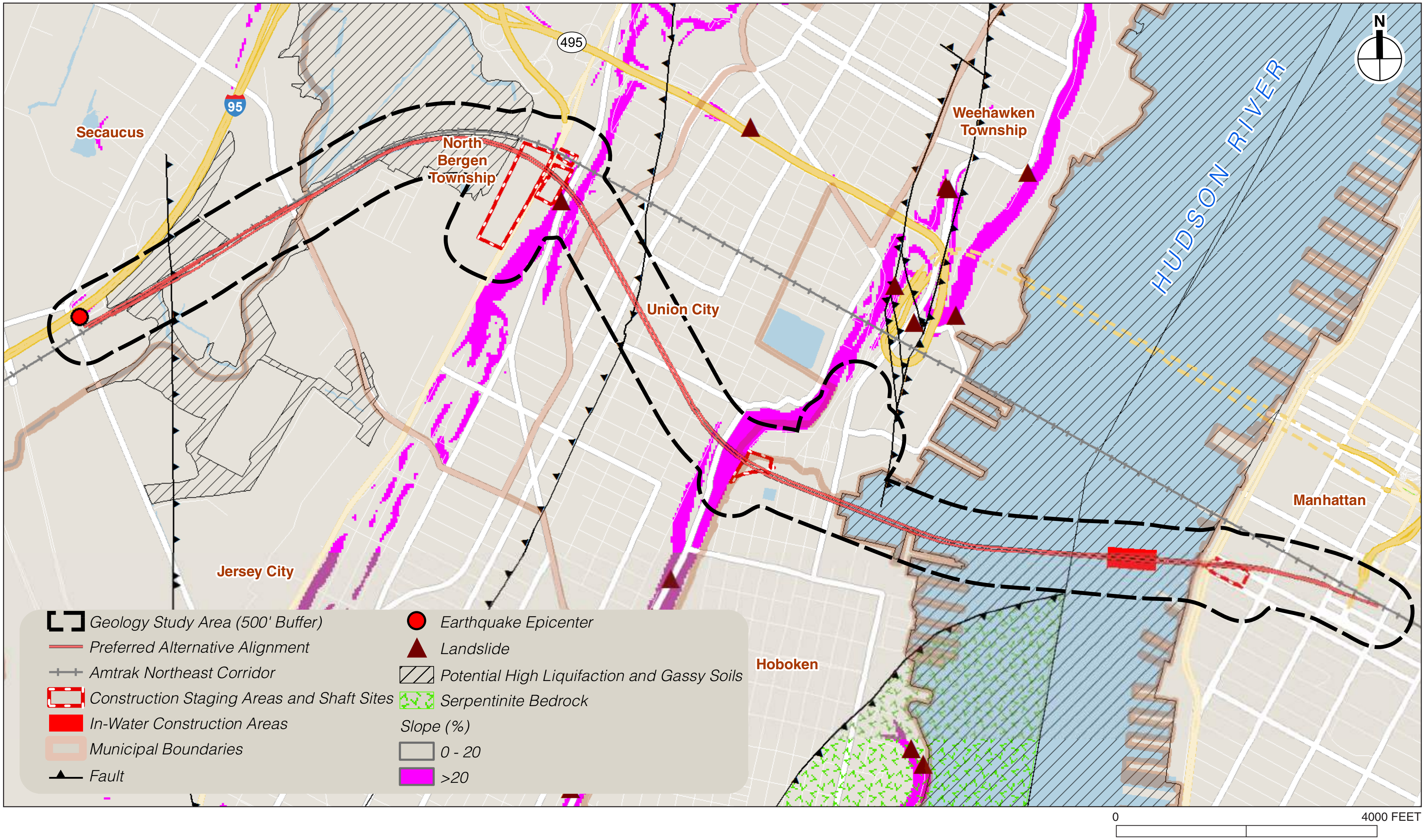
0 2,000 FEET

HUDSON TUNNEL PROJECT

Bedrock Geology in the Study Area

Figure 15-1

12.22.17



HUDSON TUNNEL PROJECT

Geologic Hazards within the Study Area

Figure 15-2

topographic ridge near the Hudson River that runs approximately north-south and rises above the surrounding lowlands of the Meadowlands.

The study area in New Jersey is underlain by rock of the Newark Basin, a thickness of over 15,000 feet of westward-dipping continental sedimentary strata composed of mudstone, siltstone, sandstone, conglomerate, and argillite deposited during the Triassic and Jurassic periods.[4] Sedimentary rock of the Newark Basin is thickest to the west adjacent to the fault-bounded Hudson Highlands and is thinner to the east where it overlays the Manhattan Schist beyond (east) of the Palisades sill. The western portal approach overlies the Lockatong and Passaic Formations, which consist of predominately shale, siltstone and mudstone with interbedded argillites, a very hard rock. The Lockatong Formation is classified as Aquifer Rank D with well yields ranging from 25 to 100 gallons per minute (GPM), whereas the Passaic Formation is classified as Aquifer Rank C[5] with well yields ranging from 101 to 250 GPM.

The Preferred Alternative's tunnel, Hoboken ventilation shaft and fan plant site would penetrate the Stockton Formation, which consists of predominately sandstone with silty mudstone, argillaceous[6] siltstone, and shale. The Stockton Formation is classified by the NJDEP, Division of Water Supply and Geoscience, as Aquifer Rank C with well yields ranging between 101 and 250 GPM. Mapped on either side of the Palisades ridge, the Lockatong Formation consists of siltstones and argillite, and within the Project area, also includes arkosic sandstone (a particular type of sandstone that contains 25 percent or more feldspar). The Palisades Sill Jurassic Diabase[7], an igneous rock also within the Project area, is the dense, resistant rock that underlies the topographically prominent Palisades ridge along the Hudson River. Serpentinite, a greenish fine-grained metamorphic rock containing a variety of naturally occurring serpentine asbestos minerals (including chrysotile and talc), has been identified along the Hudson River waterfront in Hoboken.

FRA and NJ TRANSIT obtained Monteverde and Rea's bedrock map of New Jersey[8] from the NJDEP New Jersey Geological and Water Survey. Review of the map indicates that there are geologic faults present within the bedrock near Weehawken Cove. The faults may pose a hazard to the tunnel in the event of an earthquake or other tectonic event. The presence of the fault may also result in higher dewatering volumes during construction than would typically be generated from the presence of natural fractures and jointing within the bedrock mass.

15.3.1.2 SURFICIAL GEOLOGY

In New Jersey, the overburden geology consists of glacial till, as well as post-glacial eolian,[9] alluvial, and marsh and estuarine deposits, and artificial fill. Thickness in the Project area ranges

---

4 Drake, Avery A., et al. "USGS Map I-2540-A: Bedrock Geologic Map of Northern New Jersey." 1996.

5 Aquifer recharge mapping has been used in New Jersey to develop a ranking system to display the potential for aquifer recharge. Aquifers are ranked based on the median yield of selected non-domestic well yields; with yield used as indicative of the capacity of the aquifer to supply water, which defines an aquifer. There are five ranks, A-E: E, less than 25 gallons per minute (GPM); D, 25 to 100 GPM; C, greater than 100 GPM to 250 GPM; B, greater than 250 GPM to 500 GPM; and A, greater than 500 GPM.

6 Argillaceous refers to geologic materials largely composed of or containing clay-size particles or clay minerals.

7 Diabase rock is dark in color being under-saturated with respect to silica as compared to most crustal (granitic) rocks.

8 Bedrock Geologic Map of the New Jersey Portions of the Weehawken and Central Park Quadrangles, Bergen, Hudson and Passaic Counties, New Jersey, Donald H. Monteverde and Francesca Rea (Draft).

9 Eolian refers to deposits of soil and rock that are transported and deposited as the result of wind action.

from zero in areas of rock outcrops at the Palisades and Laurel Hill to greater than 250 feet at a glacially eroded bedrock trough east of Kearny.

The till consists of clay to boulder-sized material deposited by glacial ice. The Preferred Alternative's tunnel portal is located in an area of glacial till. River delta and lake fan deposits composed of steep to gently dipping layers of fine gravel, sand, and silt, formed by glacial melt water running into glacial lakes are present along the western shore of the Hudson River in the area of the Preferred Alternative's tunnel alignment. Post-glacial marsh and estuarine deposits occur on both sides of the Palisades and comprise salt-marsh peat, organic silts and clays, and gravel.

Excavation and filling for residential, commercial, or industrial purposes have altered a large percentage of the surficial soils in the Project area. Earth and manmade materials have been placed as fill, including gravel, sand, silt, clay, trash, cinders, ash, and construction debris. Large land areas along the Hudson River shoreline in Hoboken were reclaimed by filling tidal marsh and other low-lying areas with a variety of materials, including clean granular fill, cinders, ash, shotrock (irregular-shaped angular broken stones from excavation activities) from construction of various tunnels, other construction debris, and garbage. For much of the 20th century, unregulated dumping of solid waste took place in the Meadowlands, with extensive filling of wetlands with no oversight.[10]

15.3.2 HUDSON RIVER

15.3.2.1 BEDROCK GEOLOGY

The Hudson River portion of the study area is located between the Piedmont physiographic province on the west and the Manhattan Prong of the New England Upland physiographic province on the east. The Hudson River estuary system has a channel morphology that reflects the three navigational channels maintained by the U.S. Army Corps of Engineers (USACE): a central channel authorized at a minimum 45 feet deep from Upper New York Harbor to West 59th Street; a New York channel authorized at a minimum 40 feet deep through the length of the study area; and a New Jersey channel along the Weehawken-Edgewater waterfront authorized at a minimum 40 feet deep south of Weehawken and 30 feet deep north of Weehawken.

The elevation of the bottom of the narrow, deep, glacially scoured bedrock trough surface underlying the Hudson River (extending more than 300 feet below sea level)[11] generally rises downstream toward Upper New York Harbor. Depth to rock is about 60 feet below mean low water at the New Jersey bulkhead line in Hoboken, and about 150 feet below mean low water at the New York bulkhead line in the vicinity of West 29th Street in Manhattan.

The Stockton Formation is the base sedimentary layer of the Newark basin and forms the bedrock along the western shoreline and underlying the Hudson River. The formation slopes downward to the west, and is underlain by the metamorphic bedrock of the Hartland Formation.

---

10 https://www.njsea.com/history.

11 Coch, Nicholas K., and Dennis Weiss, 1989. "Environmental Geology and Geological Development of the Lower Hudson Estuary and New York Harbor," in *Geology and Engineering Geology of the New York Metropolitan Area*, Field Trip Guidebook T361, Charles A. Baskerville, editor, 28th International Geological Congress, American Geophysical Union, Washington, D.C., pp. T361:15 – T361-25. Stanford, Scott D. 1993. Surficial Geology of the Weehawken and Central Park Quadrangles, Bergen, Hudson, and Passaic Counties, New Jersey, N.J. Geological Survey Open-File Map OFM 13, scale 1:24,000. Stanford, Scott D. 1996a. *Engineering and Environmental Geology of the Surficial Materials of the Hackensack Meadowlands and Adjacent Areas, New Jersey and New York*, Association of Engineering Geologists, 39th Annual Meeting Field Trips, East Brunswick, New Jersey, pp. D-1-D-20.

Serpentinite, a greenish fine-grained metamorphic rock containing a variety of naturally occurring serpentine asbestos minerals (including chrysotile and talc), is present along the Hudson River waterfront in Hoboken, and at locations approximately mid-channel.

15.3.2.2 SURFICIAL GEOLOGY

According to information developed in the ARC FEIS, the maximum thickness of surficial materials overlying bedrock of the Hudson River in the study area is about several hundred feet. It comprises a complex stratigraphy of glacial, river, lake, and estuarine deposits[12]. Through much of the study area, the uppermost surficial material in the Hudson River is a thick sequence of post-glacial estuarine deposits of gray, peat, organic silty clay and clayey silt with traces of fine sand and shells.[13] Many of these soils are compressible, and have a high liquefaction potential.

15.3.3 NEW YORK

15.3.3.1 BEDROCK GEOLOGY

The study area in New York is located within the Manhattan Prong of the New England Upland physiographic province. Most of the study area is underlain by schist,[14] presumably of the Hartland Formation.[15] The Hartland Formation and Manhattan Schist Formation outcrop east of the Hudson River and consist of metamorphic rocks, primarily schist and gneiss.[16] Rock in the study area in New York also includes pegmatite[17] intrusions of various ages, Silurian-age granite, and scattered serpentinite.

15.3.3.2 SURFICIAL GEOLOGY

The regional surface geology in New York City consists of glacial till overlain by silt and clay, estuarine and marsh deposits, and silty sand. The thickness of surficial materials is generally less than 50 feet across most of Manhattan, but is much thicker in the study area because the rock surface drops off steeply adjacent to the Hudson River.[18]

Surface soils along the length of the Hudson River waterfront in the study area include primarily fill, presumably reclaimed from the river. Historical records examined during the preparation of the ARC FEIS, indicate that areas along the Hudson River extend well beyond the original mid-19th century shoreline, which were filled for urban development. Typically, these areas were formerly

---

[12] Pennsylvania Railroad borings (circa 1906) undertaken for the construction of the existing North River Tunnel, *ARC FEIS*, 2008.

[13] Ibid Coch and Weiss, 1989 and Stanford, 1993; 1996; Stanford and Harper, 1991. Stanford, Scott D. and David P. Harper. 1991. “Glacial Lakes of the Lower Passaic, Hackensack, and Lower Hudson Valleys, New Jersey and New York,” *Northeastern Geology*, Vol. 13, No. 4, pp. 271-286.

[14] Schist is a foliated crystalline rock type formed during dynamic metamorphism. Schists can be broken or split into various sizes, ranging from the size of mineral flakes to slabs of rock, mainly because of the parallelism of the majority of the minerals present.

[15] Baskerville, Charles A. “USGS Map I-2306: Bedrock and Engineering Geologic Maps of New York County and Parts of King and Queens Counties, New York, and Parts of Bergen and Hudson Counties, New Jersey.” 1994.

[16] Gneiss is a foliated crystalline rock type formed during regional metamorphism. Gneisses are typically identified by alternating bands of granular minerals and flaky or elongated minerals. The bands generally alternate in color from light to dark, but depend on the minerals present.

[17] Pegmatite is similar in nature to granite rock in that it is a coarse-grained igneous rock. Grain sizes in pegmatitic rocks are much larger than those found in granitic rocks, and are generally on the order of 1 to 2 inches (or larger) in diameter.

[18] Ibid, Baskerville, 1994.

bays or tidal marshes with organic deposits found beneath the fill. Most of the surface soils have been altered by excavation, filling, or paving for residential, commercial, or industrial purposes.

15.4 AFFECTED ENVIRONMENT: FUTURE CONDITIONS

Within the Project study area, activities such as site excavation, site clearing, and landscaping for the development and maintenance of existing and proposed facilities would continue under future conditions in the absence of the Preferred Alternative. In the Hudson River, dredging and other activities for maintenance of the channels and near-shore structures would also be expected to continue under future conditions. These activities would result in changes in the built environment but would not adversely impact soils and geologic conditions within the study area or with respect to the geologic conditions described above, in Section 15.2.2, because they would not be of a sufficient scale to cause or affect these conditions. Ongoing geologic processes, such as normal erosion and sedimentation, would also continue in all parts of the study area under future conditions. The future affected environment absent the implementation of the Preferred Alternative is the baseline against which the impacts of both the No Action and Preferred Alternatives are compared.

15.5 IMPACTS OF NO ACTION ALTERNATIVE

Under the No Action Alternative, the location, characteristics, and types of soils and geologic resources would remain similar to the existing condition. Continued use, maintenance, and operation of the existing North River Tunnel, or its possible continued deterioration and eventual closure, would not affect soils or geologic resources in the area under the No Action Alternative.

15.6 CONSTRUCTION IMPACTS OF THE PREFERRED ALTERNATIVE

15.6.1 OVERVIEW

In this section, FRA and NJ TRANSIT have analyzed the potential for certain geologic conditions to be encountered within the Project area as a result of the various activities associated with construction of the new tunnel, cross passages, retaining walls, piles, embankments, rail beds and tracks, tunnel portal structures, fan plants, utilities, rail and vehicular bridges, underpass structures, cross culverts, platforms, etc. A summary of potential construction activities that could be affected by the noted geologic conditions, which in turn may dictate implementation of specific construction methods, includes the following:

- Maintaining stability of existing building foundations;
- Soil erosion and degradation;
- Tunneling through mixed-face (soil and rock mixture) and unstable bedrock;
- Disturbance of hazardous minerals (discussed and analyzed in detail in Chapter 16, “Contaminated Materials”);
- Steep slope instability from construction vibrations;
- Generation of vibrations from blasting (discussed and analyzed in detail in Chapter 12B, “Vibration”); and

- Dewatering[19] and its effect on settling of soils (discussed in Chapter 3, "Construction Methods and Activities," Chapter 11, "Natural Resources," and Chapter 16, "Contaminated Materials").

As noted above (see Section 15.2.2), studies for the ARC Project concluded liquefaction was not a concern for that project. Since the Preferred Alternative would be in the same general area and would be constructed generally through the same geologic materials as the ARC Project, liquefaction would not be a concern for the Preferred Alternative either.

15.6.2 NEW JERSEY

The design and construction methods for the Preferred Alternative would address geologic conditions in the New Jersey portion of the Project alignment during construction as follows:

- During construction of the surface alignment in soft soils in the Meadowlands, the alignment would be supported either on an embankment of imported soils supported by a retaining wall with pile foundations, or on a viaduct supported by deep piles. This would avoid the potential instability of a sloped embankment in an area of soft soils. Standard soil erosion and control measures (silt fences and barriers, and hay bale checks) would be implemented, as necessary, to prevent excavated material from leaving the work zone and entering the neighboring areas (see Chapter 16, "Contaminated Materials," Section 16.8, which describes a Project-wide soils and materials management plan).
- The Tonnelle Avenue staging area and the new tunnel portal in North Bergen would be located near the site of a previous landslide, and nearby areas may be potentially unstable and may also require slope stabilization systems. Stabilization measures, such as rock bolting and installation of surface protection, will be implemented to address the source of the landslide material located on a steep slope above the staging area and the portal itself. In addition, geotechnical investigations will be undertaken during further design stages to confirm the need and location for any additional stabilization measures.
- Construction activities around existing structures can create vibrations resulting in undermining or structural instability. To avoid such issues, new structures developed above the alignment of the Preferred Alternative, including bridges and trestles, embankments, platforms, underpass structures, rail beds, retaining structures and subsurface, and surface utilities, would be constructed to include the appropriate support to eliminate structural instability; existing structures that could be affected would be underpinned or otherwise supported to avoid displacements or undermining. The Preferred Alternative includes underpinning of the Willow Avenue bridge in Hoboken. The Project contractor would also employ vibration mitigation measures, such as controlled blasting, so as to avoid triggering landslides on steep slopes. In addition, surface settlement markers would be installed at and along the Project site to determine if construction activities are resulting in excessive settlement of the ground (and any building structures, subsurface structures, or utilities along the alignment), so that corrective measures can be implemented, as needed.
- Stripping of vegetation and subsequent ground treatment, including filling to construct or widen embankment areas, can result in soil erosion, generating sediment that could accumulate in adjacent surface water and wetlands if not properly controlled. To avoid this issue, the Project Sponsor will implement soil erosion management measures. Applicable laws and regulations pertaining to stormwater pollution prevention will be followed during construction (see discussion in Chapter 3, "Construction Methods and Activities," Section 3.2.4).

[19] Dewatering refers to the process used to remove water infiltration from an active work area.

- Ground improvement (i.e., the modification of soil properties or constructing inclusions within soil to achieve a required strength or stiffness) or foundation construction (such as for abutments, piers, retaining walls, or culverts) in some areas would require dewatering. For the Preferred Alternative, dewatering would be required in the Meadowlands area of New Jersey where the new surface alignment would be constructed and during the excavation of the new Hudson River Tunnel beneath the Palisades and the Hoboken/Weehawken waterfront area, limited inflow of groundwater is expected, which would also require dewatering measures. Dewatering would consist of setting pumps in excavations and directing water to temporary construction sedimentation basins for subsequent recharge or off-site disposal if recharge is not feasible. The dewatering of excavated high-organic content soils or sediments would require stockpiles, dust suppression, and dewatered liquid collection and disposal. Additionally, construction of culverts and bridges over a water body may require the temporary diversion of stream flow, using temporary pipes, culverts or other measures that would be determined during final design and in accordance with the applicable permit requirements. (Please refer to Chapter 3, “Construction Methods and Activities,” Sections 3.2.2 and 3.2.4, and Chapter 16, “Contaminated Materials,” Section 16.8, for additional information about dewatering, ground improvement techniques, and handling of dewatered/excavated soils.)
- At the Hoboken staging area, where the shaft and fan plant would be constructed below the groundwater table, to avoid potential destabilization of soils that could occur from lowering of the groundwater table, slurry walls extending into rock would be used for excavation support to cut off groundwater inflow at the Hoboken shaft. As an additional groundwater cutoff measure, a grouting program to fill cracks and other voids in the rock mass below and adjacent to the shaft may be required in order to minimize groundwater inflow.
- As discussed in Chapter 2, “Project Alternatives and Description of the Preferred Alternative,” Section 2.5.2, and illustrated in that chapter in Figure 2-5, the new Hudson River Tunnel would begin at the base (toe) of the cliff in North Bergen and then descend beneath the Palisades so that when it reaches the Hoboken/Weehawken border at the eastern edge of the Palisades rock mass, the new tunnel would be approximately 80 feet below ground level. The new tunnel’s two tubes would be lined with bolted precast concrete segment rings immediately following excavation; the lining material would be waterproof, and therefore no change in groundwater seepage patterns would result from introduction of the tunnel into the rock mass. Nonetheless, to protect against instability of the eastern cliff face of the Palisades, Amtrak has undertaken mapping of the cliff face during preliminary engineering for the new Hudson River Tunnel. Prior to construction, the Project’s final design will include further evaluation of unstable loosened areas and implementation of a vibration monitoring program to address ground movement during construction (see Chapter 12B, “Vibration,” Section 12B.9.4).
- To avoid triggering landslides on steep slopes in this area, the Project contractor would employ vibration mitigation measures, such as controlled blasting where needed for the underground tunnel. Slope inclinometers will be used for installation in areas where slopes are known—or have been known—to be unstable. Vibratory ground motion during construction of the Preferred Alternative would occur from mechanical rock excavation or blasting; the Project Sponsor will implement a vibration monitoring program as described in Chapter 12B, “Vibration,” Section 12B.9.4. Lower vibration limits may be applied near sensitive structures or environments as necessary. Construction Protection Plans (CPPs) will be developed for the protection of historic architectural resources located in proximity to Project construction prior to any Project demolition, excavation, and construction activities. The CPPs will include provisions for vibration monitoring, adherence to vibration limit thresholds, measures to reduce vibration levels, and modification of construction methods if necessary. Controlled blasting techniques will be used, and if monitoring during test blasts indicates that allowable peak particle velocity limits may be exceeded, blast patterns and methods will be modified to reduce vibrations to an acceptable level. Vibration monitoring will continue during rock

excavation operations. In addition, best management practices (BMPs) related to landslide prevention would be implemented to minimize the potential for landslides, including regular inspections, maintenance of infrastructure, roadways and vegetation, and other BMPs developed specifically for the area.

- The excavated material from tunneling would be managed in accordance with a site-specific soil and materials management plan (SMMP), as described in more detail in Chapter 16, “Contaminated Materials,” Section 16.8.
- Construction of the Hoboken fan plant and ventilation shaft may require intermittent drilling and blasting followed by removal of soils. The shaft would be installed through the Stockton Formation sandstone which includes a very hard argillaceous siltstone layer.
- For construction at the Hoboken shaft site in New Jersey, jet grouting of the overburden compressible soils and permeation grouting of the rock would be used to minimize the need for dewatering and maintain existing groundwater levels in the area surrounding the shaft to minimize settlements.
- Due to the presence of known and mapped faults in the Weehawken Cove area, tunnel excavation would use a sealed pressurized-face Tunnel Boring Machine (TBM) specially designed for counteracting simultaneously both water and soil inflows. This condition is expected along the tunnel alignment through Hoboken, Weehawken Cove, and the entire Hudson River. In addition, the Project includes a cross passage in rock in this area that would be constructed after the two tubes of the new tunnel are excavated. In this area, the Project contractor performing the cross passage work would be informed by data about any potential inflow areas from prior TBM performance in this area. In addition, the contract documents will require the Project contractor to first probe through the cross passage length using horizontal drilling to further evaluate existing and potential inflow areas that may affect tunneling and stability of the geology. If the probes identify issues that could affect tunneling and geological stability, the Project Sponsor will ensure that modifications to the construction methods to address the issues are implemented.
- For construction of the Hudson River Tunnel, serpentinite bedrock containing naturally occurring asbestos (NOA) may be encountered during tunnel boring operations as the TBMs approach the Hoboken waterfront and move under the river. When drilling, excavation, or boring activities occur in serpentinite, airborne dust resulting from these activities can contain microscopic asbestos particles that could present a health concern. Mitigation measures for encountering NOA minerals are discussed below in Section 15.8 and in Chapter 16, “Contaminated Materials.”
- For rehabilitation of the existing North River Tunnel, demolition activities would be confined to the interior of the existing tunnel, and material deliveries and removal of debris would occur in New Jersey at the Tonnelle Avenue staging site. No new excavation or ground disturbance would occur for the rehabilitation effort; therefore, this aspect of the Preferred Alternative would have no effect on the geology or soils in the study area.

15.6.3 HUDSON RIVER

The design and construction methods for the Preferred Alternative would address geologic conditions in the Hudson River during construction as follows:

- Serpentinite bedrock containing NOA minerals may be present and would be hazardous if dust-borne. Mitigation measures for encountering NOA minerals are discussed in Section 15.8 and in Chapter 16, “Contaminated Materials.”
- Because of the geological conditions in the new tunnel segment from the Hoboken shaft to Manhattan running under the Hudson River, the TBMs used for this segment of the new tunnel

will be mixed-face TBMs, as described in Chapter 3, “Construction Methods and Activities,” in Section 3.2.1.1.

- Since the tunnel boring methods generate a viscous liquid consisting of water-based drilling fluids and ground-up geologic materials, the wet spoil material would first need to dry before it is transported off-site (see Chapter 3, “Construction Methods and Activities,” Section 3.3.2.4, for a discussion of disposal of excavated material).
- Dewatering would be controlled by limiting the amount of permissible groundwater drawdown since surrounding soils can settle from uncontrolled groundwater drawdown. The TBM tunnels provide very good groundwater control since the permanent and waterproof tunnel lining is constructed by the TBM as it moves forward, but limited inflow of groundwater is expected, which would also require dewatering measures. The non-TBM tunnels and shafts would use ground treatment that mitigates groundwater drawdown in compressible soils.
- Near-shore tunnel boring in river sediments may encounter pilings used for both ground stabilization and to support existing structures along the waterfront areas. The available ground modification or ground improvement methods, which ultimately would be chosen by the Project contractor, include: jet grouting, deep soil mixing, ground freezing, permeation grouting, and chemical grouting. The use of these construction methods have been evaluated in the various relevant sections of the EIS, where such techniques would result in potential environmental impacts (e.g., jet grouting and deep soil mixing effects are evaluated in Chapter 11, “Natural Resources”). Temporary ground support consisting of some combination of rock bolts, shotcrete, steel channels, steel ribs, lagging, and similar methods would be used to support the new tunnel sections. Dewatering would be less in the event that precast concrete segments would be assembled into rings as the tunnel construction advances. The excavated material from tunneling would require transport and disposal; management of contaminated soil and the corresponding applicable laws and regulations are discussed in Chapter 16, “Contaminated Materials,” Sections 16.2.1 and 16.8.
- As the tunnel approaches Manhattan, tunneling activities would be relatively shallow beneath the river bottom. Near the Manhattan shoreline, an area of low cover would require soil improvement in this portion of the river bottom to address the construction risks before the TBM excavation occurs (described in detail in Chapter 3, “Construction Methods and Activities,” Sections 3.2.2 and 3.3.5.2). After the soil is hardened, the TBM could safely pass through the improved soils.
- The existing Manhattan bulkhead located near Twelfth Avenue consists of riprap and a timber pile foundation system. The bulkhead area would be subjected to permeation grouting and ground freezing techniques, with the potential for manual removal of portions of the bulkhead structure in advance of TBM mining, to enable the TBM to pass through the bulkhead area. The ground treatment technique proposed for the area between the bulkhead, Hudson River Park, and the east side of Twelfth Avenue is a combination of soil freezing and grouting, which could be combined with sequential excavation method mining and backfilling of the excavation area between the bulkhead and Twelfth Avenue with material suitable for the TBM to pass through.

15.6.4 NEW YORK

The design and construction methods for the Preferred Alternative in New York would address geologic conditions in the Project site during construction as follows:

- Serpentinite bedrock containing asbestos minerals may be present and would be hazardous if dust-borne, as discussed above (Section 15.6.2). Mitigation measures for encountering NOA minerals are discussed in Section 15.8.

- Groundwater drawdown would be strictly controlled in the same manner as described for the New Jersey and Hudson River segments (Sections 15.6.2 and 15.6.3, respectively).
- A vibration monitoring program would be instituted as described in Chapter 12B, “Vibration,” Section 12B.9.4.
- The Twelfth Avenue shaft would be constructed to approximately 80 feet below grade through the existing fill consisting of a fine to coarse sand, and soft silt-clay mixture. Bedrock is estimated to be 120 feet below grade here. Construction would require a water-tight earth retaining wall system, such as a diaphragm (slurry) wall. The soils between the excavation bottom and the top of rock (approximately 40 feet) would require ground treatment to control excavation stability and groundwater drawdown (as described in detail in Chapter 3, “Construction Methods and Activities,” Section 3.2.2).
- The Preferred Alternative includes selective underpinning and/or relocation of support columns for the building at 450 West 33rd Street in Manhattan.

15.7 PERMANENT IMPACTS OF THE PREFERRED ALTERNATIVE

The Preferred Alternative would result in minimal permanent impacts to geologic resources in the study area from construction of the new tunnel. The New Jersey, Hudson River, and New York portions of the Project area for the new Hudson River Tunnel would have very similar long-term effects. The Preferred Alternative would remove soil and rock through either tunnel boring or cut-and-cover construction from construction of the new tunnel. The soil surface would also be exposed in portal and vent shaft locations, requiring stabilization to limit soil erosion and surface runoff to the Hudson River. Surficial soil within the study area would not likely be adversely impacted by the Preferred Alternative, as the area is already highly urbanized and previously disturbed.

Permanent ground treatment would be minimized (3.0 acres) to facilitate construction of the new Hudson River Tunnel in the area of low cover within the Hudson River.

The existing geologic structures, faults, bedrock, soils, seismic and geologic stability and native material surrounding excavations would not be adversely impacted and would not experience long-term changes as a result of the operation of the Preferred Alternative.

In addition, the rehabilitation of the existing North River Tunnel would not affect soils or geologic resources in the study area, as the rehabilitation does not involve any ground disturbance.

The design of the Preferred Alternative would account for the potential long-term effects of geological conditions on the Project. These measures are described in detail in Section 15.8 of this chapter. The Project Sponsor will account for seismic factors, including effects of soil behavior, in the Project design. Structures will be designed in accordance with the established seismic design criteria to resist a specified level of shaking, including a maximum design earthquake load. Liquefaction potential will be rechecked to confirm previous conclusions that liquefaction is not an issue. If different new conclusions are reached regarding liquefaction, then appropriate design changes will be made.

15.8 MEASURES TO AVOID, MINIMIZE, AND MITIGATE IMPACTS

The Preferred Alternative will include a number of measures to be incorporated into its final design, to avoid, minimize, or mitigate impacts to and from geologic or soil conditions, which the Project Sponsor will implement during construction. The lead Federal agency will be responsible for ensuring that the Project Sponsor implements these measures, which will be identified in the ROD. The measures described below are described in greater detail in Chapter 3, "Construction Methods and Activities," and in other relevant analysis areas. These measures are consistent with those identified as part of the ARC FEIS, and are still applicable, which generally address the geologic and/or soil conditions that would need to be accounted for in the design and construction of the Preferred Alternative.

15.8.1 NEW JERSEY

- To account for the potential for undermining settlement or structural instability due to excavation beneath or adjacent to existing railroad, roadway, utility structures, or other existing foundations within the construction zone in New Jersey, the Project will include underpinning or otherwise supporting them and monitoring for movements as excavation progresses. The Preferred Alternative includes underpinning of the Willow Avenue bridge in Hoboken. Excavation and construction methods will be modified if monitoring indicates that movements exceed established limits. Support may include modular walls, secant pile walls, or soldier piles and lagging. In addition to providing sidewall support, these lateral retention methods would assist in groundwater control for the excavation.
- Where protective vegetation would be removed during construction, the Project contractor will implement erosion control measures to prevent adverse impacts to erodible soils due to increased runoff. Erosion control measures may include a combination of silt fences, hay bales, diversion ditches, temporary grading, and vegetative or other protective coverings for exposed soils. A soil erosion and sediment control plan will be prepared and implemented in accordance with all applicable standards and regulations.
- The Project design will account for seismic factors, including effects of soil behavior. Structures will be designed in accordance with the established seismic design criteria to resist a specified level of shaking, including a maximum design earthquake load. Liquefaction potential will be rechecked to confirm previous conclusions that liquefaction is not an issue. If different new conclusions are reached regarding liquefaction, then appropriate design changes will be made.
- Given the presence of faults in the Weehawken Cove area, for the cross passage to be constructed here, the contract documents will require the Project contractor to first probe through the entire cross passage length using horizontal drilling to further evaluate potential inflow areas.
- If faults are encountered during construction of the Palisades tunnel, the Hoboken shaft, or the western portion of the river tunnel, the Project contractor will perform ground stabilization measures such as grouting ahead of the excavation face to stabilize the ground and/or control groundwater inflow. Additional rock support (e.g., rock bolts, shotcrete, or other measures) may also be used.
- To mitigate vibrations generated during rock excavation at the Palisades tunnel portal, cross passages, and the Hoboken shaft site, the Project Sponsor will implement a vibration monitoring program, as described in Chapter 12B, "Vibration," Section 12B.9.4. Controlled blasting techniques will be used, and if monitoring during test blasts indicate that allowable peak particle velocity limits may be exceeded, blast patterns and methods will be modified to reduce vibrations to an acceptable level. Vibration monitoring will continue during rock excavation operations.
- The Project Sponsor will develop CPPs for the protection of historic architectural resources located in proximity to Project construction prior to any Project demolition, excavation, and construction activities. The CPPs will include provisions for vibration monitoring, adherence to

vibration limit thresholds, measures to reduce vibration levels, and modification of construction methods if necessary.

- Prior to the commencement of construction, the Project Sponsor will evaluate the stability of rock slopes in the vicinity of the Palisades tunnel portal and the Hoboken shaft and fan plant site to determine if any of the slopes on either side of the Palisades are unstable and susceptible to shifting during construction. If locations of instability are identified, the Project Sponsor will develop and implement slope stabilization at the necessary locations. Stabilization measures, such as rock bolting and installation of surface protection, will be implemented to address the source of the landslide material located on a steep slope above the staging area and the portal itself. In addition, geotechnical investigations will be undertaken during further design stages to confirm the need and location for any additional stabilization measures.
- The Project Sponsor will implement best management practices (BMPs) related to landslide prevention to minimize the potential for landslides, including regular inspections, maintenance of infrastructure, roadways and vegetation, and other BMPs developed specifically for the area.
- During the excavation of any portion of the new Hudson River Tunnel, if serpentinite or other rock that could contain potentially hazardous asbestiform minerals is encountered, the Project contractor will implement measures to protect workers and the public, as well as to minimize any environmental hazard associated with excavated material removal and processing. NOA is not subject to the same framework of Federal, state, and local requirements as asbestos containing materials (ACM), which are products, such as insulation materials, made from NOA. While there is no specific Federal or state guidance related to handling of NOA, since NOA can be harmful to human health, implementing prudent measures to avoid and reduce exposure, as would be appropriate for ACM, is recommended. Therefore, measures to mitigate worker and public exposure to NOA would be implemented as part of a Project-wide Soils and Materials Management Plan (SMMP) (see Chapter 16, “Contaminated Materials”). Typical engineering controls involve the use of covers and caps, vegetation, fencing, landscaping, and in some conditions, the application of water to suppress dust. Common work practices include limiting activities on NOA-containing areas, reducing driving speed on unpaved roads that may contain NOA, and cleaning vehicles driven over NOA. Worker health and safety measures that include respiratory protection may also be warranted. In addition, any on-site reuse, beneficial reuse or off-site disposal of any such asbestos-containing rock would, at a minimum, be conducted in accordance with Federal and state regulations. There is no specific New Jersey or New York State guidance for the handling of NOA: however, since NOA can be harmful to human health, implementing prudent measures to avoid and reduce exposure, as would be appropriate for ACM, is common practice.
- To minimize dust hazards during excavation of the Palisades tunnel and the Hoboken shaft, and in processing and transport of excavated materials, the Project contractor will implement dust control measures, as further discussed in Chapter 13, “Air Quality,” and Chapter 16, “Contaminated Materials.”
- To minimize potential ground displacement resulting from excessive and/or uncontrolled dewatering in the vicinity of the Hoboken shaft site, the Project contractor will implement control measures, including ground improvement to stabilize soils, installation of slurry walls or other lateral earth retention in areas of open cut or shaft construction, or underpinning of potentially affected existing structures, as necessary. Surface settlement markers would be installed and used to quantify if excessive settlement is occurring as a result of construction.

15.8.2 HUDSON RIVER

- The Project Sponsor will account for both low-cover and seismic factors, including effects of soil behavior, in the Project design for proposed surface and subsurface structures. Structures in and under the Hudson River will be designed in accordance with the established seismic design criteria to resist an appropriate level of shaking, including a maximum design earthquake load.
- During the excavation of any portion of the new Hudson River Tunnel, if serpentinite or other rock that could contain potentially hazardous asbestiform minerals is encountered, the Project contractor will implement measures as discussed above in Section 15.8.1.

15.8.3 NEW YORK

- The Project contractor will implement erosion control measures where pavement would be removed during construction to prevent adverse impacts to erodible soils. Construction will be performed in accordance with standards and specifications for selection, design, and implementation of erosion and sediment control practices contained in the latest version of *New York State Guidelines for Urban Erosion and Sediment Control*.
- The Project Sponsor will account for seismic factors, including effects of soil behavior, in the Project design, and will incorporate measures to address these factors in proposed surface and subsurface structures. Structures will be designed in accordance with the established seismic design criteria to resist an appropriate level of shaking, including a maximum design earthquake load.
- If faulting or poor quality rock is present at the proposed Tenth Avenue cut-and-cover site, the Project contractor will use rock grouting, rock bolting, and shotcrete, if necessary, to allow excavation in closely fractured or weathered rock.
- To mitigate vibration impacts generated during excavation or other construction activities, the Project Sponsor will implement a vibration monitoring program, that will include action thresholds, as described in Chapter 12B, “Vibration,” Section 12B.9.4.
- To minimize dust hazards during excavation of the Manhattan tunnel and the Twelfth Avenue shaft, and in processing and transport of excavated materials, the Project contractor will implement dust control measures, as further discussed in Chapter 13, “Air Quality.”
- During the excavation of any portion of the Manhattan tunnel, if serpentinite or other rock which would contain potentially hazardous asbestiform minerals is encountered, the Project contractor will implement measures as discussed above in Section 15.8.1.
- To minimize potential ground displacement resulting from dewatering in the vicinity of New York excavation areas, the Project contractor will implement control measures, including ground improvement to stabilize soils, rock mass grouting, installation of waterproof earth retention systems, such as slurry walls or other lateral earth retention in areas of open cut or shaft construction, or underpinning of potentially affected existing structures, would be implemented, as necessary. Surface settlement markers will be installed and used to quantify if excessive settlement is occurring as a result of construction. ✷