I-70/I-71 SOUTH INNERBELT
FRA-70-8.93 PID 77369

SPECIAL REPORT

CONSTRUCTION VIBRATION ANALYSIS

2009 -- 2010

HARRIS MILLER MILLER & HANSON INC.
1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Shiloh Baptist Church from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 1 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the noise impact assessment methodology and results.

1.1 Construction and Site Description

The Shiloh Baptist Church is an old and historic building located adjacent to the I-71/I-670 Interchange in Columbus, OH. As shown in the photograph in Figure 1, the building is of brick construction and is in somewhat fragile condition. The construction activity that will take place closest to the church building consists of drilled shaft installation for Retaining Wall N11. This wall will be located approximately 50 feet from the building at the closest point. There is also a bridge to be constructed approximately 200 feet west of the building that could involve driving piles.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground vibration levels at the church from the planned construction activities are not expected to exceed applicable criteria for damage to sensitive buildings. However, there is the potential for construction vibrations to be annoying to building occupants when drilled shaft construction occurs within 90 feet from the church and when impact pile driving occurs within 520 feet from the church. Vibration mitigation measures that can be considered include scheduling construction work to avoid drilled shaft construction within 90 feet of the building during sensitive activities at the church and by using alternative bridge construction methods to limit impact pile driving within 520 feet from the building.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level (LV) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual.\(^1\) Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard\(^2\) that has been used on major construction projects in the USA. For the most sensitive building category, which applies to buildings such as the Shiloh Baptist Church that are extremely susceptible to vibration damage, the recommended criterion is 0.12 in/sec in terms of PPV, which approximately corresponds to 90 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For institutional land uses with primarily daytime use, such as the church, the recommended criterion is 75 VdB for frequent events (more than 70 vibration events per day).

3.2 Vibration Projection Methodology

Construction vibration projections at the church are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[
PPV_{\text{equip}} = PPV_{\text{ref}} \times \left( \frac{25}{D} \right)^n
\]  
\(\text{(Eq. 1)}\)

where:

- \(PPV_{\text{equip}}\) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \(PPV_{\text{ref}}\) is the reference vibration level at 25 feet = 0.089 in/sec for caisson drilling
  = 0.644 in/sec for impact pile driving
- \(D\) is the distance from the equipment to the receiver in feet
- \(n\) is a propagation coefficient based on soil class = 1.5 for normal propagation conditions

Because the soil boring log closest to the church building (B-216) indicates the presence of hard, stiff silt, clay and sand, an adjustment to the “\(n\)” value was made to account for potentially more efficient vibration propagation through the soil. Values for “\(n\)” have been developed from field construction data,\(^3\) indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied for this assessment.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[
L_v(D) = L_v(25 \text{ ft}) - a \log(D/25)
\]  
\(\text{(Eq. 2)}\)

where:

- \(L_v(D)\) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \(L_v(25 \text{ ft})\) is the reference vibration level at 25 ft = 87 VdB for caisson drilling
  = 104 VdB for impact pile driving
- \(D\) is the distance from the receiver in feet
- \(a\) is an attenuation factor based on soil class = 30 for normal propagation conditions

To account for potentially more efficient vibration propagation through the hard soil at this site, an “\(a\)” value of 22 has been applied for this assessment instead of the value of 30 used for normal propagation. This value is consistent with the “\(n\)” value of 1.1 used for PPV in Equation 1 above.

---


3.3 Assessment

Using Equation 1, the PPV at the church building for drilled shaft construction at the closest distance of 50 feet from the retaining wall is projected to be 0.04 in/sec. For impact pile driving related to bridge construction at a distance of 200 feet, the PPV is projected to be 0.07 in/sec. In either case, the projected PPV values are below the most stringent criterion of 0.12 in/sec for vibration damage effects. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the $L_v$ at the church building for drilled shaft construction at the closest distance of 50 feet from the retaining wall is projected to be 80 VdB. For impact pile driving related to bridge construction at a distance of 200 feet, the $L_v$ is projected to be 84 VdB. In both cases, the maximum projected vibration levels exceed the FTA annoyance criterion of 75 VdB. Thus, there is the potential for construction vibrations to be annoying to building occupants when drilled shaft construction occurs within 90 feet from the church and when impact pile driving occurs within 520 feet from the church.

3.4 Mitigation

Vibration mitigation measures that can be considered to minimize annoyance include scheduling construction work to avoid drilled shaft construction within 90 feet of the building during sensitive activities at the church and by using alternative bridge construction methods to limit impact pile driving within 520 feet from the building. Alternatives to impact pile driving that can be investigated include the use of drilled piles or the use of static load equipment to push rather than drive piles if the geological conditions permit.
1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Saint Paul AME Church from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 2 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the vibration impact assessment methodology and results.

1.1 Construction and Site Description

The Saint Paul AME Church is an old and historic building located on the west side of the highway I-71 cut section at Long Street in Columbus, OH. As shown in the photograph in Figure 1, the building is of brick construction and is in reasonably good condition. The construction activities that will take place closest to the church building consist of bottom-up MSE wall construction for Retaining Wall N5 as well as trench wall construction (with either cast-in-place footings or drilled shafts) for the Long Street Bridge. Major vibration-generating equipment for MSE wall construction includes vibratory rollers and bulldozers. For the bridge construction, major vibration-generating equipment includes either vibratory rollers for cast-in-place footings or drill augers for drilled shafts. Both the wall and the bridge abutments will be located approximately 100 feet from the building at the closest point.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground vibration levels at the church from the planned construction activities are not expected to exceed the applicable building damage criterion. However, there is the potential for construction vibrations to be annoying to building occupants during either MSE retaining wall construction or trench wall construction with cast-in-place footings for the Long Street Bridge when vibratory rollers are used within 185 feet from the church. A vibration mitigation measure that can be considered is scheduling construction work to avoid the use of vibratory rollers within 185 feet of the building during sensitive activities at the church. Also, operation of this equipment can be avoided entirely during bridge construction by using drilled shafts rather than cast-in-place footings.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level (Lv) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual.\textsuperscript{1} Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard\(^2\) that has been used on major construction projects in the USA. For Category III, which applies to non-engineered timber and masonry buildings such as the Saint Paul AME Church, the recommended criterion is 0.2 in/sec in terms of PPV, which approximately corresponds to 94 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For institutional land uses with primarily daytime use, such as the church, the recommended criterion is 75 VdB for frequent events (more than 70 vibration events per day).

3.2 Vibration Projection Methodology

Construction vibration projections at the church are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[
PPV_{equi} = PPV_{ref} \times (25/D)^n \quad \text{(Eq. 1)}
\]

where:
- \(PPV_{equi}\) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \(PPV_{ref}\) is the reference vibration level at 25 feet = 0.210 in/sec for vibratory rollers
  = 0.089 in/sec for bulldozers or drill augers
- \(D\) is the distance from the equipment to the receiver in feet
- \(n\) is a propagation coefficient based on soil class = 1.5 for normal propagation conditions

Because the soil boring log closest to the church building (B-202) indicates the presence of stiff, hard silt, clay, an adjustment to the “\(n\)” value was made to account for potentially more efficient vibration propagation through the soil. Values for “\(n\)” have been developed from field construction data,\(^3\) indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied for this assessment.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[
L_v(D) = L_v(25\ ft) - a \log(D/25) \quad \text{(Eq. 2)}
\]

where:
- \(L_v(D)\) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \(L_v(25\ ft)\) is the reference vibration level at 25 ft = 94 VdB for vibratory rollers
  = 87 VdB for bulldozers or drill augers
- \(D\) is the distance from the receiver in feet
- \(a\) is an attenuation factor based on soil class = 30 for normal propagation conditions

To account for potentially more efficient vibration propagation through the hard soil at this site, an “\(a\)” value of 22 has been applied for this assessment instead of the value of 30 used for normal propagation. This value is consistent with the “\(n\)” value of 1.1 used for PPV in Equation 1 above.


3.3 Assessment

The highest vibration levels at the church building would be generated by the use of vibratory rollers during MSE wall construction and during bridge construction with cast-in-place footings. Using Equation 1, the highest PPV at the church building for vibratory rollers at the closest distance of 100 feet is projected to be 0.05 in/sec. Thus, the projected PPV values at the church building for all construction activities are below the applicable criterion of 0.2 in/sec for vibration damage effects. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the $L_v$ at the church building at the closest distance of 100 feet is projected to be 81 VdB for vibratory rollers and 74 VdB for bulldozers or augers. Thus, vibratory rollers are projected to generate vibration levels that exceed the vibration annoyance criterion of 75 VdB when operating close to the building. Based on the relationship in Equation 2, it is estimated that there is the potential for construction vibrations to be annoying to building occupants when vibratory rollers are used for either MSE wall construction or bridge construction with cast-in-place footings within 185 feet from the church.

3.4 Mitigation

As indicated above in Section 3.3, there is the potential for construction vibrations to be annoying to building occupants during MSE wall or bridge construction. A vibration mitigation measure that can be considered to minimize annoyance is scheduling construction work to avoid the use of vibratory rollers within 185 feet of the building during sensitive activities at the church. Also, operation of this equipment can be avoided entirely during bridge construction by using drilled shafts rather than cast-in-place footings.
TECHNICAL MEMORANDUM

To: Karel Cubick, ms consultants
From: David A. Towers, HMMH
Date: February 11, 2010
Subject: Construction Vibration Impact Assessment at Site 3 – Belmont Apartments
         I-70/I-71 South Innerbelt Corridor Project – Columbus, OH
Reference: HMMH Project No. 303390

1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Belmont Apartments from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 3 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the impact assessment methodology and results.

1.1 Construction and Site Description

The Belmont Apartments is an historic residential building located on the west side of the highway I-71 cut section at Lester Drive and Town Street in Columbus, OH. As shown in the photograph in Figure 1, the building is of brick construction and is in reasonably good condition. The construction activities that will take place closest to the building consist of drilled shaft construction for Retaining Wall N1 as well as trench wall construction (with either cast-in-place footings or drilled shafts) for the Lester Deck. Major vibration-generating equipment for retaining wall construction includes drill augers and bulldozers that will be located about 35 feet from the building at the closest point. For the deck construction, major vibration-generating equipment includes either vibratory rollers for cast-in-place footings or drill augers for drilled shafts that will be located approximately 70 feet from the building at the closest point.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground vibration levels at the apartments from the planned construction activities are not expected to exceed the applicable building damage criterion. However, there is the potential for construction vibrations to be annoying to building occupants during drilled shaft retaining wall or bridge deck construction when drill augers or bulldozers are used within 120 feet from the apartments or during bridge deck construction with cast-in-place footings when vibratory rollers are used within 250 feet from the apartments. A vibration mitigation measure that can be considered is limiting the use of drill augers, bulldozers and vibratory rollers near the building to the daytime hours. Also, operation of vibratory rollers can be avoided entirely during bridge deck construction by using drilled shafts rather than cast-in-place footings.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level (LV) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
3. **VIBRATION IMPACT ASSESSMENT**

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual.\(^1\) Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard that has been used on major construction projects in the USA. For Category III, which applies to non-engineered timber and masonry buildings such as the Belmont Apartments, the recommended criterion is 0.2 in/sec in terms of PPV, which approximately corresponds to 94 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For residential land uses, such as the apartments, the recommended criterion is 72 VdB for frequent events (more than 70 vibration events per day).

3.2 Vibration Projection Methodology

Construction vibration projections at the church are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[ PPV_{\text{equip}} = PPV_{\text{ref}} \times (25/D)^n \]  

(Eq. 1)

where:
- \( PPV_{\text{equip}} \) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \( PPV_{\text{ref}} \) is the reference vibration level at 25 feet = 0.210 in/sec for vibratory rollers  
  = 0.089 in/sec for bulldozers or drill augers
- \( D \) is the distance from the equipment to the receiver in feet
- \( n \) is a propagation coefficient based on soil class = 1.5 for normal propagation conditions

Because the soil boring logs closest to the church building (B-183 and B-186) indicate the presence of stiff, hard silt and clay above dense sand and gravel, an adjustment to the “n” value was made to account for potentially more efficient vibration propagation through the soil. Values for “n” have been developed from field construction data, indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied here.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[ L_v(D) = L_v(25 \text{ ft}) – a \log(D/25) \]  

(Eq. 2)

where:
- \( L_v(D) \) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \( L_v(25 \text{ ft}) \) is the reference vibration level at 25 ft = 94 VdB for vibratory rollers  
  = 87 VdB for bulldozers or drill augers
- \( D \) is the distance from the receiver in feet
- \( a \) is an attenuation factor based on soil class = 30 for normal propagation conditions

To account for potentially more efficient vibration propagation through the hard soil at this site, an “a” value of 22 has been applied for this assessment instead of the value of 30 used for normal propagation. This value is consistent with the “n” value of 1.1 used for PPV in Equation 1 above.

---


3.3 Assessment

The highest vibration levels at the church building would be generated by the use of drill augers during retaining wall construction and vibratory rollers during bridge deck construction with cast-in-place footings. Using Equation 1, the highest PPV values at the apartments are projected to be 0.06 in/sec. for drill augers or bulldozers at the closest distance of 35 feet and 0.07 in/sec. for vibratory rollers at the closest distance of 70 feet. Thus, the projected PPV values at the apartment building for all construction activities are below the applicable criterion of 0.2 in/sec for vibration damage effects. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the $L_v$ at the apartment building is projected to be 84 VdB for drill augers at the closest distance of 35 feet as well as for vibratory rollers at the closest distance of 70 feet. Thus, these sources are projected to generate vibration levels that exceed the vibration annoyance criterion of 72 VdB when operating close to the building. Based on the relationship in Equation 2, it is estimated that there is the potential for construction vibrations to be annoying to building occupants during drilled shaft retaining wall or bridge deck construction when drill augers or bulldozers are used within 120 feet from the apartments or during bridge deck construction with cast-in-place footings when vibratory rollers are used within 250 feet from the apartments.

3.4 Mitigation

As indicated above in Section 3.3, there is the potential for construction vibrations to be annoying to building occupants during drilled shaft retaining wall or bridge deck construction. A vibration mitigation measure that can be considered is avoiding the use of drill augers, bulldozers and vibratory rollers near the building during the nighttime hours. Also, operation of vibratory rollers can be avoided entirely during bridge deck construction by using drilled shafts rather than cast-in-place footings.
TECHNICAL MEMORANDUM

To: Karel Cubick, ms consultants
From: David A. Towers, HMMH
Date: February 11, 2010
Subject: Construction Vibration Impact Assessment at Site 4 – Children’s Hospital
I-70/I-71 South Innerbelt Corridor Project – Columbus, OH
Reference: HMMH Project No. 303390

1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Children’s Hospital Orthopedic Center from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 4 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the impact assessment methodology and results.

1.1 Construction and Site Description

The Children’s Hospital Orthopedic Center is a newer medical building located south of the I-70/I-71 Interchange at Parsons Avenue in Columbus, OH. As shown in the photograph in Figure 1, the building is of concrete and masonry construction and is in very good condition. The construction activity that will take place closest to the church building consists of MSE wall construction for Retaining Wall I-8, including the use of vibratory rollers and bulldozers at a distance of approximately 150 feet from the building at the closest point. There are also bridge structures with pile-supported footings that will be constructed nearby, involving impact pile driving as close as 420 feet from the building.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground vibration levels at the orthopedic center from the planned construction activities are not expected to exceed applicable building damage criteria. However, there is the potential for construction vibrations to be annoying to building occupants during retaining wall construction when vibratory rollers are used within 185 feet from the building and during bridge construction when pile driving occurs within 520 feet from the building. In addition, there is the potential for construction activities to interfere with vibration-sensitive medical equipment during retaining wall construction when vibratory rollers are used within 520 feet from the building or when bulldozers are used within 250 feet from the building, and during bridge construction when pile driving occurs within about 1,500 feet from the building. Vibration mitigation measures that can be considered include scheduling construction work to avoid these activities near the building during sensitive activities at the orthopedic center and by using alternative bridge construction methods to limit impact pile driving near the building.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level (L_v) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual. Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects and for interference with sensitive equipment use. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard\textsuperscript{2} that has been used on major construction projects in the USA. For Category II, which applies to engineered concrete and masonry buildings such as the Children’s Hospital Orthopedic Center, the recommended criterion is 0.3 in/sec in terms of PPV, which approximately corresponds to 98 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For institutional land uses with primarily daytime use, such as the orthopedic center, the recommended criterion is 75 VdB for frequent events (more than 70 vibration events per day). However, if the building contains moderately-sensitive equipment such as optical microscopes, the recommended criterion to avoid interference is 65 VdB.

3.2 Vibration Projection Methodology

Construction vibration projections at the church are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[
PPV_{\text{equip}} = PPV_{\text{ref}} \times (25/D)^n
\]  
\text{(Eq. 1)}

where:
- \(PPV_{\text{equip}}\) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \(PPV_{\text{ref}}\) is the reference vibration level at 25 feet
  - 0.089 in/sec for bulldozers
  - 0.210 in/sec for vibratory rollers
  - 0.644 in/sec for impact pile driving
- \(D\) is the distance from the equipment to the receiver in feet
- \(n\) is a propagation coefficient based on soil class
  - 1.5 for normal propagation conditions
  - 1.1 for “hard” soils

Because the soil boring logs closest to the church building (B-142, B-143 and B-144) indicate the presence of very stiff, hard, silt and clay above medium-dense sand, an adjustment to the “\(n\)” value was made to account for potentially more efficient vibration propagation through the soil. Values for “\(n\)” have been developed from field construction data,\textsuperscript{3} indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied for this assessment.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[
L_v(D) = L_v(25\ ft) – a \log(D/25)
\]  
\text{(Eq. 2)}

where:
- \(L_v(D)\) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \(L_v(25\ ft)\) is the reference vibration level at 25 ft
  - 87 VdB for caisson drilling
  - 94 VdB for vibratory rollers
  - 104 VdB for impact pile driving
- \(D\) is the distance from the receiver in feet
- \(a\) is an attenuation factor based on soil class
  - 30 for normal propagation conditions

\textsuperscript{2} Association of Swiss Highway Professionals, Committee VSS 272, “The Effects of Vibrations on Constructed Facilities,” Swiss Standard SN640312a, April 1992.

To account for potentially more efficient vibration propagation through the hard soil at this site, an “a” value of 22 has been applied for this assessment instead of the value of 30 used for normal propagation. This value is consistent with the “n” value of 1.1 used for PPV in Equation 1 above.

3.3 Assessment

Using Equation 1, the PPV at the orthopedic center for the use of vibratory rollers for MSE wall construction at the closest distance of 150 feet as well as for impact pile driving at the closest distance of 420 feet is projected to be 0.03 in/sec. In either case, the projected PPV values are well below the applicable criterion of 0.3 in/sec. for vibration damage effects. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the $L_v$ at the orthopedic center for MSE wall construction at the closest distance of 150 feet is projected to be 77 VdB during the use of vibratory rollers and 70 VdB during the use of bulldozers. For impact pile driving related to bridge construction at a distance of 420 feet, the $L_v$ is projected to be 77 VdB at the building. In both cases, the maximum projected vibration levels marginally exceed the FTA annoyance criterion of 75 VdB and significantly exceed the sensitive equipment criterion of 65 VdB.

Based on the relationship in Equation 2, it is estimated that there is the potential for construction vibrations to be annoying to building occupants and to interfere with vibration-sensitive medical equipment during retaining wall construction when vibratory rollers are used within 185 feet from the building and during bridge construction when pile driving occurs within 520 feet from the building. In addition, there is also the potential for construction activities to interfere with vibration-sensitive medical equipment during retaining wall construction when vibratory rollers are used within 520 feet from the building or when bulldozers are used within 250 feet from the building, and during bridge construction when pile driving occurs within about 1,500 feet from the building.

3.4 Mitigation

As indicated above in Section 3.3, there is the potential for construction vibrations to be annoying to building occupants and to interfere with vibration-sensitive medical equipment during retaining wall and bridge construction. Vibration mitigation measures that can be considered to minimize annoyance and interference include scheduling construction work to avoid the major vibration-generating activities near the building during sensitive activities at the orthopedic center and by using alternative bridge construction methods to avoid impact pile driving within 520 feet from the building. Alternatives to impact pile driving that can be investigated include the use of drilled piles or the use of static load equipment to push rather than drive piles if the geological conditions permit.
1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Africentric School from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 5 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the vibration impact assessment methodology and results.

1.1 Construction and Site Description

The Africentric School is an historic school building located on the south side of the highway I-70 cut section to the north of Livingston Avenue in Columbus, OH. As shown in the photograph in Figure 1, the building is of brick construction and is in reasonably good condition. The construction activity that will take place nearest the building consists of drilled shaft construction for Retaining Wall 6W5. Major vibration-generating equipment for retaining wall construction includes drill augers and bulldozers that will be located about 30 feet from the building at the closest point.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground vibration levels at the school from the planned construction activities are not expected to exceed the applicable building damage criterion. However, there is the potential for construction vibrations to be annoying to building occupants during drilled shaft construction when drill augers or bulldozers are used within 90 feet from the school. A vibration mitigation measure that can be considered is limiting the use of drill augers and bulldozers near the building during school hours.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level ($L_v$) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual.\(^1\) Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard\(^2\) that has been used on major construction projects in the USA. For Category III, which applies to non-engineered concrete and masonry buildings such as the Africentric School, the recommended criterion is 0.2 in/sec in terms of PPV, which approximately corresponds to 94 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For institutional land uses, such as the school, the recommended criterion is 75 VdB for frequent events (more than 70 vibration events per day).

3.2 Vibration Projection Methodology

Construction vibration projections at the church are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[
PPV_{\text{equip}} = PPV_{\text{ref}} \times (25/D)^n \quad \text{(Eq. 1)}
\]

where:
- \(PPV_{\text{equip}}\) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \(PPV_{\text{ref}}\) is the reference vibration level at 25 feet = 0.089 in/sec for bulldozers or augers
- \(D\) is the distance from the equipment to the receiver in feet
- \(n\) is a propagation coefficient based on soil class = 1.5 for normal propagation conditions

Because the soil boring log closest to the school building (B-040) indicates the presence of medium to very stiff silt and clay above dense gravel and sand, an adjustment to the “\(n\)” value was made to account for potentially more efficient vibration propagation through the soil. Values for “\(n\)” have been developed from field construction data,\(^3\) indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied here.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[
L_v(D) = L_v(25 \text{ ft}) – a \log(D/25) \quad \text{(Eq. 2)}
\]

where:
- \(L_v(D)\) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \(L_v(25 \text{ ft})\) is the reference vibration level at 25 ft = 94 VdB for vibratory rollers
  = 87 VdB for bulldozers or drill augers
- \(D\) is the distance from the receiver in feet
- \(a\) is an attenuation factor based on soil class = 30 for normal propagation conditions

To account for potentially more efficient vibration propagation through the hard soil at this site, an “\(a\)” value of 22 has been applied for this assessment instead of the value of 30 used for normal propagation. This value is consistent with the “\(n\)” value of 1.1 used for PPV in Equation 1 above.

---


3.3 Assessment

The highest vibration levels at the school building would be generated by the use of drill augers and bulldozers during retaining wall construction. Using Equation 1, the highest PPV values at the apartments are projected to be 0.07 in/sec. for drill augers or bulldozers at the closest distance of 30 feet. Thus, the projected PPV values at the school building for all construction activities are below the applicable criterion of 0.2 in/sec for vibration damage effects. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the L_v at the school building is projected to be 85 VdB at the closest distance of 30 feet for drill augers and bulldozers. Thus, these sources are projected to generate vibration levels that exceed the vibration annoyance criterion of 75 VdB when operating close to the building. Based on the relationship in Equation 2, it is estimated that there is the potential for construction vibrations to be annoying to building occupants during drilled shaft retaining wall construction when drill augers or bulldozers are used within 90 feet from the school.

3.4 Mitigation

As indicated above in Section 3.3, there is the potential for construction vibrations to be annoying to building occupants during drilled shaft retaining wall construction. A vibration mitigation measure that can be considered is avoiding the use of drill augers and bulldozers within 90 feet of the building during school hours.
TECHNICAL MEMORANDUM

To: Karel Cubick, ms consultants
From: David A. Towers, HMMH
Date: April 6, 2010
Subject: Construction Vibration Impact Assessment at Site 6 – Franklin Co. Courthouse
I-70/I-71 South Innerbelt Corridor Project – Columbus, OH

Reference: HMMH Project No. 303390

1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Franklin County Courthouse from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 6 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the impact assessment methodology and results.

1.1 Construction and Site Description

The Franklin County Courthouse is a large modern building located on the north side of the highway I-70 cut section between S. Front Street and S. High Street in Columbus, OH. As shown in the photograph in Figure 1, the building is of new concrete and steel construction and is in very good condition. The construction activities that will take place closest to the building consist of drilled shaft construction for Retaining Wall 7W2 as well as trench wall construction (with either cast-in-place footings or drilled shafts) for the Front Street and High Street bridges. Major vibration-generating equipment for retaining wall construction includes drill augers that will be located about 50 feet from the building at the closest point. For the bridge construction, major vibration-generating equipment includes either vibratory rollers for cast-in-place footings or drill augers for drilled shafts that will be located approximately 50 feet and 115 feet from the building at the closest point for the Front and High Street bridges, respectively.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground-borne vibration levels at the courthouse from the planned construction activities are not expected to exceed the applicable criteria for either building damage or annoyance. Thus, vibration mitigation measures are not anticipated for construction at this location.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level (Lv) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
### 3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual.\(^1\) Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

### Figure 2. Typical Ground-Borne Vibration Levels and Criteria

<table>
<thead>
<tr>
<th>Human/Structural Response</th>
<th>Velocity Level* (VdB)</th>
<th>Typical Sources (50 ft from source)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold, minor cosmetic damage, fragile buildings</td>
<td>100</td>
<td>Blasting from construction projects</td>
</tr>
<tr>
<td>Difficulty with tasks such as reading a VDT screen</td>
<td>90</td>
<td>Bulldozers and other heavy tracked construction equipment</td>
</tr>
<tr>
<td>Residential annoyance, infrequent events (e.g. commuter rail)</td>
<td>80</td>
<td>Commuter rail, upper range</td>
</tr>
<tr>
<td>Residential annoyance, frequent events (e.g. rapid transit)</td>
<td>70</td>
<td>Rapid transit, upper range</td>
</tr>
<tr>
<td>Limit for vibration sensitive equipment. Approx. threshold for human perception of vibration</td>
<td>60</td>
<td>Commuter rail, typical</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>Bus or truck over bump</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rapid transit, typical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus or truck, typical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Typical background vibration</td>
</tr>
</tbody>
</table>

\(^*\) RMS Vibration Velocity Level in VdB relative to \(10^{-6}\) inches/second

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard\textsuperscript{2} that has been used on major construction projects in the USA. For Category I, which applies to reinforced concrete and steel buildings such as the Franklin County Courthouse, the recommended criterion is 0.5 in/sec in terms of PPV, which approximately corresponds to 102 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For institutional land uses, such as the courthouse, the recommended criterion is 75 VdB for frequent events (more than 70 vibration events per day).

3.2 Vibration Projection Methodology

Construction vibration projections at the courthouse are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[
PPV_{\text{equip}} = PPV_{\text{ref}} \times (25/D)^n
\]  

(Eq. 1)

where:
- \(PPV_{\text{equip}}\) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \(PPV_{\text{ref}}\) is the reference vibration level at 25 feet = 0.210 in/sec for vibratory rollers = 0.089 in/sec for drill augers
- \(D\) is the distance from the equipment to the receiver in feet
- \(n\) is a propagation coefficient based on soil class = 1.5 for normal propagation conditions

Values for “\(n\)” have been developed from field construction data,\textsuperscript{3} indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions. Because the soil borings closest to the courthouse (B-027 and B-028) indicate the presence of dense gravel, sand and silt, this value is considered to be applicable at this location.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[
L_v(D) = L_v(25 \text{ ft}) - a \log(D/25) - C
\]  

(Eq. 2)

where:
- \(L_v(D)\) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \(L_v(25 \text{ ft})\) is the reference vibration level at 25 ft = 94 VdB for vibratory rollers = 87 VdB for drill augers
- \(D\) is the distance from the receiver in feet
- \(a\) is an attenuation factor based on soil class = 30 for normal propagation conditions
- \(C\) is an adjustment factor for the coupling of ground vibration to the building foundation

For the large courthouse building structure, the coupling factor “\(C\)” is taken to be 10 VdB based on FTA guidance for generalized predictions of ground-borne vibration.

\textsuperscript{2} Association of Swiss Highway Professionals, Committee VSS 272, “The Effects of Vibrations on Constructed Facilities,” Swiss Standard SN640312a, April 1992.

3.3 Assessment

The highest vibration levels at the courthouse building would be generated by the use of drill augers during retaining wall construction and vibratory rollers during bridge construction with cast-in-place footings. Using Equation 1, the highest PPV values at the courthouse are projected to be 0.03 in/sec for drill augers at the closest distance of 50 feet and 0.07 in/sec for vibratory rollers at the closest distance of 50 feet. Thus, the projected PPV values at the courthouse building for all construction activities are well below the applicable criterion of 0.5 in/sec for vibration damage effects. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the $L_v$ at the courthouse building is projected to be 68 VdB for drill augers at the closest distance of 50 feet and 75 VdB for vibratory rollers at the closest distance of 50 feet. Thus, these sources are not projected to generate vibration levels that exceed the vibration annoyance criterion of 75 VdB when operating close to the building.

3.4 Mitigation

As indicated above in Section 3.3, vibration levels are not expected to exceed the applicable criteria for damage or annoyance for either retaining wall or bridge construction. Thus, vibration mitigation measures are not anticipated for construction at this location.
TECHNICAL MEMORANDUM

To: Karel Cubick, ms consultants

From: David A. Towers, HMMH

Date: April 6, 2010

Subject: Construction Vibration Impact Assessment at Site 7–Juvenile Detention Center
I-70/I-71 South Innerbelt Corridor Project – Columbus, OH

Reference: HMMH Project No. 303390

1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Juvenile Detention Center from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 7 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the impact assessment methodology and results.

1.1 Construction and Site Description

The Juvenile Detention Center is a large modern building located on the north side of the highway I-70 cut section near S. Front Street in Columbus, OH. As shown in the photograph in Figure 1, the building is of new concrete and steel construction and is in very good condition. The construction activities that will take place closest to the building consist of MSE wall construction for Retaining Wall 7W1 as well as trench wall construction (with either cast-in-place footings or drilled shafts) for the Ramp F1 crossover bridge. Major vibration-generating equipment for retaining wall construction includes the use of vibratory rollers and bulldozers at a distance of approximately 20 feet from the building at the closest point. For the bridge construction, major vibration-generating equipment includes either vibratory rollers for cast-in-place footings or drill augers for drilled shafts that will be located at a distance of about 75 feet from the building at the closest point.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground vibration levels at the Juvenile Detention Center are not expected to exceed applicable building damage criteria for either retaining wall or bridge construction. However, there is the potential for construction vibrations to be annoying to building occupants during retaining wall construction or during bridge construction with cast-in-place footings when vibratory rollers are used within 90 feet from the building, or during retaining wall construction when bulldozers are used within 40 feet from the building. A vibration mitigation measure that can be considered is limiting these activities near the building to the daytime hours. Also, operation of vibratory rollers can be avoided entirely during bridge construction by using drilled shafts rather than cast-in-place footings.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level (Lw) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
### 3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual.\(^1\) Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard\(^2\) that has been used on major construction projects in the USA. For Category I, which applies to reinforced concrete and steel buildings such as the Juvenile Detention Center, the recommended criterion is 0.5 in/sec in terms of PPV, which approximately corresponds to 102 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For land uses with nighttime occupancy, such as the detention center, the recommended criterion is 72 VdB for frequent events (more than 70 vibration events per day).

3.2 Vibration Projection Methodology

Construction vibration projections at the building are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[
PPV_{\text{equip}} = PPV_{\text{ref}} \times (25/D)^n
\]  
\hspace{1cm} (Eq. 1)

where:

- \(PPV_{\text{equip}}\) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \(PPV_{\text{ref}}\) is the reference vibration level at 25 feet = 0.210 in/sec for vibratory rollers = 0.089 in/sec for bulldozers or drill augers
- \(D\) is the distance from the equipment to the receiver in feet
- \(n\) is a propagation coefficient based on soil class = 1.5 for normal propagation conditions

Because the soil borings closest to the detention center (B-025 and B-026) indicate the presence of hard to very stiff silt and clay, an adjustment to the “\(n\)” value was made to account for potentially more efficient vibration propagation through the soil. Values for “\(n\)” have been developed from field construction data,\(^3\) indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied for this site.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[
L_v(D) = L_v(25 \text{ ft}) – a \log(D/25) – C
\]  
\hspace{1cm} (Eq. 2)

where:

- \(L_v(D)\) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \(L_v(25 \text{ ft})\) is the reference vibration level at 25 ft = 94 VdB for vibratory rollers = 87 VdB for bulldozers or drill augers
- \(D\) is the distance from the receiver in feet
- \(a\) is an attenuation factor based on soil class = 30 for normal propagation conditions
- \(C\) is an adjustment factor for the coupling of ground vibration to the building foundation

To account for potentially more efficient vibration propagation through the hard soil at this site, an “\(a\)” value of 22 has been applied for this assessment instead of the value of 30 used for normal propagation. This value is consistent with the “\(n\)” value of 1.1 used for PPV in Equation 1 above. Also, for the large courthouse building structure, the coupling factor “\(C\)” is taken to be 10 VdB based on FTA guidance for generalized predictions of ground-borne vibration.


3.3 Assessment

The highest vibration levels at the detention center building would be generated by the use of vibratory rollers during retaining wall construction. Using Equation 1, the highest PPV values at detention center are projected to be 0.27 in/sec for vibratory rollers at the closest distance of 20 feet. Thus, the projected PPV values at the detention center building for all construction activities are below the applicable criterion of 0.5 in/sec for vibration damage effects. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the $L_v$ at the detention center building is projected to be 86 VdB for vibratory rollers and 79 VdB for bulldozers during retaining wall construction at the closest distance of 20 feet and 74 VdB for vibratory rollers during bridge construction with cast-in-place footings at the closest distance of 75 feet. Thus, these sources are projected to generate vibration levels that exceed the vibration annoyance criterion of 72 VdB when operating close to the building. Based on the relationship in Equation 2, it is estimated that there is the potential for construction vibrations to be annoying to building occupants during retaining wall construction or during bridge construction with cast-in-place footings when vibratory rollers are used within 90 feet from the building, or during retaining wall construction when bulldozers are used within 40 feet from the building. However, if drilled shafts are used for bridge construction, the $L_v$ at the detention center building is projected to be 67 VdB, below the annoyance criterion.

3.4 Mitigation

As indicated above in Section 3.3, there is the potential for construction vibration to be annoying to building occupants during retaining wall construction and during bridge construction with cast-in-place footings when vibratory rollers are used within 90 feet of the building or when bulldozers are used within 40 feet of the building. Thus, a vibration mitigation measure that can be considered is avoiding these activities within these distances. Also, operation of vibratory rollers can be avoided entirely during bridge construction by using drilled shafts rather than cast-in-place footings.
TECHNICAL MEMORANDUM

To: Karel Cubick, ms consultants
From: David A. Towers, HMMH
Date: April 6, 2010
Subject: Construction Vibration Impact Assessment at Site 8 – Trinity Lutheran Church
I-70/I-71 South Innerbelt Corridor Project – Columbus, OH
Reference: HMMH Project No. 303390

1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Trinity Lutheran Church from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 8 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the impact assessment methodology and results.

1.1 Construction and Site Description

The Trinity Lutheran Church is an historic building located on the north side of the highway I-70 cut section at Third Street and Fulton Street in Columbus, OH. As shown in the photograph in Figure 1, the building is of brick construction and is in reasonably good condition. The construction activities that will take place closest to the building consist of drilled soldier pile installation for Retaining Wall 7W4 as well as trench wall construction (with either cast-in-place footings or drilled shafts) for the Third Street Bridge. Major vibration-generating equipment for retaining wall construction includes drill augers that will be located about 95 feet from the building at the closest point. For the bridge construction, major vibration-generating equipment includes either vibratory rollers for cast-in-place footings or drill augers for drilled shafts that will be located approximately 100 feet from the building at the closest point.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground vibration levels at the church from the planned construction activities are not expected to exceed the applicable building damage criterion. However, there is the potential for construction vibrations to be annoying to building occupants during bridge deck construction with cast-in-place footings when vibratory rollers are used within 185 feet from the church. A vibration mitigation measure that can be considered is avoiding the use of this equipment near the building during sensitive activities at the church. Also, operation of vibratory rollers can be avoided entirely during bridge construction by using drilled shafts rather than cast-in-place footings.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level ($L_v$) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual. The vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard\(^2\) that has been used on major construction projects in the USA. For Category III, which applies to non-engineered timber and masonry buildings such as the Trinity Lutheran Church, the recommended criterion is 0.2 in/sec in terms of PPV, which approximately corresponds to 94 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For institutional land uses, such as the church, the recommended criterion is 75 VdB for frequent events (more than 70 vibration events per day).

3.2 Vibration Projection Methodology

Construction vibration projections at the church are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[
PPV_{\text{equip}} = PPV_{\text{ref}} \times (25/D)^n
\]  

where:
- \(PPV_{\text{equip}}\) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \(PPV_{\text{ref}}\) is the reference vibration level at 25 feet = 0.210 in/sec for vibratory rollers
  = 0.089 in/sec for drill augers
- \(D\) is the distance from the equipment to the receiver in feet
- \(n\) is a propagation coefficient based on soil class = 1.5 for normal propagation conditions

Because the soil borings closest to the church building (B-033 and B-034) indicate the presence of stiff, dense gravel, sand and silt, an adjustment to the “\(n\)” value was made to account for potentially more efficient vibration propagation through the soil. Values for “\(n\)” have been developed from field construction data,\(^3\) indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied here.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[
L_v(D) = L_v(25 \text{ ft}) - a \log(D/25)
\]  

where:
- \(L_v(D)\) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \(L_v(25 \text{ ft})\) is the reference vibration level at 25 ft = 94 VdB for vibratory rollers
  = 87 VdB for drill augers
- \(D\) is the distance from the receiver in feet
- \(a\) is an attenuation factor based on soil class = 30 for normal propagation conditions

To account for potentially more efficient vibration propagation through the hard soil at this site, an “\(a\)” value of 22 has been applied for this assessment instead of the value of 30 used for normal propagation. This value is consistent with the “\(n\)” value of 1.1 used for PPV in Equation 1 above.


3.3 Assessment

The highest vibration levels at the church building would be generated by the use of drill augers during retaining wall construction and vibratory rollers during bridge deck construction with cast-in-place footings. Using Equation 1, the highest PPV values at the church are projected to be 0.02 in/sec for drill augers at the closest distance of 95 feet and 0.05 in/sec for vibratory rollers at the closest distance of 100 feet. Thus, the projected PPV values at the church building for all construction activities are well below the applicable criterion of 0.2 in/sec for vibration damage effects. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the $L_v$ at the church building is projected to be 74 VdB for drill augers at the closest distance of 95 feet and 81 VdB for vibratory rollers at the closest distance of 100 feet. Thus, only the vibratory rollers are projected to generate vibration levels that exceed the vibration annoyance criterion of 75 VdB when operating close to the building. Based on the relationship in Equation 2, it is estimated that there is the potential for construction vibrations to be annoying to building occupants during bridge deck construction with cast-in-place footings when vibratory rollers are used within 185 feet from the church.

3.4 Mitigation

As indicated above in Section 3.3, there is the potential for construction vibrations to be annoying to building occupants during bridge deck construction with cast-in-place footings. A vibration mitigation measure that can be considered is avoiding the use of vibratory rollers within 185 feet of the building during sensitive activities at the church. Also, operation of vibratory rollers can be avoided entirely during bridge construction by using drilled shafts rather than cast-in-place footings.
To: Karel Cubick, ms consultants
From: David A. Towers, HMMH
Date: April 6, 2010
Subject: Construction Vibration Impact Assessment at Site 9 – Hoster Stack
I-70/I-71 South Innerbelt Corridor Project – Columbus, OH

1. INTRODUCTION AND SUMMARY

This memorandum summarizes an assessment of the potential vibration impacts at the Hoster Stack from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage effects from the planned construction activities at this location, denoted as Site 9 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the impact assessment methodology and results.

1.1 Construction and Site Description

The Hoster Stack is a tall, historic structure located on the south side of the highway I-70 cut section near Second Street in Columbus, OH. As shown in the photograph in Figure 1, the stack is of brick and stone masonry construction and is in fair condition. The construction activities that will take place closest to the stack consist of drilled shaft construction for Retaining Wall 6W1 as well as trench wall construction with drilled shafts for the Ramp F1 crossover bridge. Major vibration-generating equipment includes drill augers that will be located about 35 feet from the stack at the closest point for retaining wall construction and approximately 40 feet from the stack at the closest point for bridge construction.

1.2 Summary of Results

The results of the assessment indicate that the maximum projected ground-borne vibration levels at the Hoster Stack are not expected to exceed the applicable conservative damage criterion for either retaining wall or bridge construction. Thus, vibration mitigation measures are not anticipated for construction at this location.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-born vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level (L_v) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual.¹ Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard that has been used on major construction projects in the USA. For Category IV, the most sensitive category which applies to structures such as the Hoster Stack that may be susceptible to vibration damage, the recommended criterion is 0.12 in/sec in terms of PPV, which approximately corresponds to 90 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level.

3.2 Vibration Projection Methodology

Construction vibration projections at the Hoster Stack are based on the method given in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

$$PPV_{eq} = PPV_{ref} \times (25/D)^n$$  \hspace{1cm} (Eq. 1)

where:
- $PPV_{eq}$ is the peak particle velocity in in/sec of the equipment adjusted for distance
- $PPV_{ref}$ is the reference vibration level at 25 feet = 0.089 in/sec for drill augers
- $D$ is the distance from the equipment to the receiver in feet
- $n$ is a propagation coefficient based on soil class = 1.5 for normal propagation conditions

Because the soil boring closest to the stack (B-024) indicates the presence of stiff clay and silt with dense silt, gravel and sand below, an adjustment to the “n” value was made to account for potentially more efficient vibration propagation through the soil. Values for “n” have been developed from field construction data, indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied for this site.

3.3 Assessment

The highest vibration levels at the Hoster Stack would be generated by the use of drill augers during retaining wall construction and during bridge construction with drilled shafts. Using Equation 1, the highest PPV values at the stack are projected to be 0.05-0.06 in/sec for drill augers at the closest distances of 35 to 40 feet. Thus, the maximum projected ground-borne vibration levels at the Hoster Stack are not expected to exceed the conservative damage criterion of 0.12 in/sec for retaining wall construction or for bridge construction with drilled shafts. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

3.4 Mitigation

As indicated above in Section 3.3, the projected vibration levels are not expected to exceed the applicable conservative damage criterion for either retaining wall or bridge construction. Thus, vibration mitigation measures are not anticipated for construction at this location.

---


**TECHNICAL MEMORANDUM**

**To:**  Karel Cubick, ms consultants  
**From:**  David A. Towers, HMMH  
**Date:**  April 6, 2010  
**Subject:**  Construction Vibration Impact Assessment at Site 10 – Miranova Complex  
I-70/I-71 South Innerbelt Corridor Project – Columbus, OH  
**Reference:**  HMMH Project No. 303390

1. **INTRODUCTION AND SUMMARY**

This memorandum summarizes an assessment of the potential vibration impacts at the Miranova complex from the planned construction activities associated with the Columbus South Innerbelt Project. This assessment was carried out for the Ohio Department of Transportation (ODOT) by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to ms consultants, inc. The objective of the assessment is to evaluate the potential for damage and annoyance effects from the planned construction activities at this location, denoted as Site 10 of ten sites to be evaluated under this subcontract. A construction and site description as well as a summary of results are provided below, followed by a discussion of vibration basics and a description of the impact assessment methodology and results.

1.1 **Construction and Site Description**

The Miranova complex is a newer development located north of highway I-70 at Mound Street and Miranova Place in Columbus, OH. As shown in the photograph in Figure 1, the development includes a garage structure, office building and condominium building, all of modern concrete and masonry construction. The construction activities that will take place closest to the development consist of (1) MSE wall construction for a portion of Ramp G3 including the use of vibratory rollers at minimum distances of 60 feet from the garage and 180 feet from the office building, (2) impact pile driving for the Ramp M1 pier foundations at minimum distances of 20 feet from the garage, 140 feet from the office building and 180 feet from the condominiums, (3) impact pile driving for the Ramp G1 abutments at minimum distances of 60 feet from the garage, 190 feet from the office building and 230 feet from the condominiums and (4) drilled shaft construction for the Ramp G1 pier foundations including the use of drill augers at minimum distances of 50 feet from the garage, 220 feet from the office building and 180 feet from the condominiums.

1.2 **Summary of Results**

The results of the assessment indicate that the maximum projected ground vibration levels at the Miranova development from the planned construction activities are not expected to exceed the applicable building damage criterion, except at the garage during impact pile driving for the closest Ramp M1 pier foundation. There is also the potential for construction vibrations to be annoying to building occupants during impact pile driving for the Ramp M1 pier foundation closest to the office building and for the Ramp G3 abutment foundation closest to the condominiums, although the projected building vibration levels only marginally exceed the applicable criteria at these locations. The potential for vibration impact can be avoided by using drilled piles rather than driven piles for the pier and abutment foundations closest to each of the three structures at the Miranova complex.
2. VIBRATION FUNDAMENTALS AND DESCRIPTORS

Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental vibration (roughly 5-100 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transportation and construction projects.

The most common measure used to quantify vibration amplitude is the peak particle velocity (PPV, in in/sec), defined as the maximum instantaneous peak of the vibratory motion. PPV is typically used in monitoring blasting and other types of construction-generated vibration, since it is related to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response, which is better related to the average vibration amplitude. In such cases, ground-borne vibration is usually characterized in terms of the “smoothed” root mean square (RMS) vibration velocity level (L_v) in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception threshold is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.
3. VIBRATION IMPACT ASSESSMENT

A vibration impact assessment was carried out in accordance with the guidelines provided in the U.S. Federal Transit Administration (FTA) guidance manual.1 Vibration impact criteria, projection methodology, assessment and mitigation are described in the sub-sections below.

---

3.1 Vibration Criteria

The FTA guidance manual provides construction vibration criteria for potential damage effects as well as vibration criteria for annoyance effects. The vibration damage criteria depend on the building sensitivity category and are taken from a Swiss Standard\(^2\) that has been used on major construction projects in the USA. For Category I, which applies to reinforced concrete and steel structures such as those at the Miranova complex, the recommended criterion is 0.5 in/sec in terms of PPV, which approximately corresponds to 102 VdB (re 1 micro-inch/second) in terms of RMS vibration velocity level. The FTA criteria for vibration annoyance are based on land use category and the frequency of vibration events. For land uses with primarily daytime occupancy, such as the office building, the recommended criterion is 75 VdB for frequent events (more than 70 vibration events per day). For residential land use such as the condominium building, a criterion of 72 VdB would apply.

3.2 Vibration Projection Methodology

Construction vibration projections at the Miranova complex are based on the method in the FTA guidance manual. The ground vibration prediction equation used for the damage assessment is as follows:

\[
PPV_{\text{equip}} = PPV_{\text{ref}} \times (25/D)^n
\]

where:
- \(PPV_{\text{equip}}\) is the peak particle velocity in in/sec of the equipment adjusted for distance
- \(PPV_{\text{ref}}\) is the reference vibration level at 25 feet
  - 0.210 in/sec for vibratory rollers
  - 0.644 in/sec for impact pile driving
  - 0.089 in/sec for drill augers
- \(D\) is the distance from the equipment to the receiver in feet
- \(n\) is a propagation coefficient based on soil class
  - 1.5 for normal propagation conditions
  - 1.1 for “hard” soils

Because the soil borings closest to the Miranova complex (B-017, B-018 and B-020) indicate the presence of stiff silt and clay, an adjustment to the “\(n\)” value was made to account for potentially more efficient vibration propagation through the soil. Values for “\(n\)” have been developed from field construction data\(^3\), indicating a value of 1.5 for “competent” soils, consistent with the FTA value for normal propagation conditions, and a value of 1.1 for “hard” soils that has been applied for this analysis.

For the assessment of vibration annoyance, the following ground vibration prediction equation was used:

\[
L_v(D) = L_v(25 \text{ ft}) – a \log(D/25) – C
\]

where:
- \(L_v(D)\) is the RMS vibration velocity level (VdB) of the equipment adjusted for distance
- \(L_v(25 \text{ ft})\) is the reference vibration level at 25 ft
  - 94 VdB for vibratory rollers
  - 104 VdB for impact pile driving
  - 87 VdB for drill augers
- \(D\) is the distance from the receiver in feet
- \(a\) is an attenuation factor based on soil class
  - 30 for normal propagation conditions
- \(C\) is an adjustment factor for the coupling of ground vibration to the building foundation

---


To account for potentially more efficient vibration propagation through the hard soil at this site, an “a” value of 22 has been applied for this assessment instead of the value of 30 used for normal propagation. This value is consistent with the “n” value of 1.1 used for PPV in Equation 1 above. Also, for the large structures at the Miranova complex, the coupling factor “C” is taken to be 10 VdB based on FTA guidance for generalized predictions of ground-borne vibration.

### 3.3 Assessment

Using Equation 1, the PPV from the use of vibratory rollers for MSE wall construction at a distance of 60 feet from the closest structure (the garage) is projected to be 0.08 in/sec. Similarly, the PPV from the use of drill augers for drilled shaft construction of the Ramp G3 pier foundations is projected to be 0.04 in/sec a distance of 50 feet from the garage. In both cases, the projected PPV values are well below the applicable criterion of 0.5 in/sec for vibration damage effects. However, the PPV from impact pile driving at a distance of 20 feet from the garage for the closest Ramp M1 pier foundation is projected to be 0.8 in/sec which exceeds the damage criterion. As stated in the Swiss Standard, the probability of slight damage is low if the vibrations are below the guideline values. However, it should be noted that soil settlement and other soil deformation mechanisms can also cause damage to constructed facilities and that such deformations cannot be evaluated based on vibration.

Using Equation 2, the highest vibration levels (L_v) at the office building are projected to be 65 VdB during MSE wall construction for Ramp G3 using vibratory rollers at the closest distance of 60 feet, and 78 VdB during impact pile driving for the closest Ramp M1 pier foundation at a distance of 140 feet. At the condominium building, the highest vibration levels are projected to be 58 VdB during drilled shaft construction for the closest Ramp G3 pier at a distance of 180 feet and 73 VdB during impact pile driving for the closest Ramp G3 abutment foundation. Thus, the maximum projected vibration levels marginally exceed the FTA annoyance criterion of 75 VdB at the office building and 72 VdB at the condominiums for pile driving at the foundation locations closest to these buildings.

### 3.4 Mitigation

As indicated above in Section 3.3, the maximum projected ground vibration levels at the Miranova complex from the planned construction activities are not expected to exceed the applicable building damage criterion, except at the garage during impact pile driving for the closest Ramp M1 pier foundation. There is also the potential for construction vibrations to be annoying to building occupants during impact pile driving for the Ramp M1 pier foundation closest to the office building and for the Ramp G3 abutment foundation closest to the condominiums, although the projected building vibration levels only marginally exceed the applicable criteria at these buildings. The potential for vibration impact can be avoided by using drilled piles rather than driven piles for the pier and abutment foundations closest to each of the three structures at the Miranova complex.