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January 6, 2020

Ms. Roberta Dwyer
Minnesota Department of Transportation
1123 Mesabi Avenue
Duluth, MN 55811

Twin Ports Interchange PCCS
AET Project No. 07-20369

LETTER TRANSMITTAL NO. 2

Dear Ms. Dwyer:

Enclosed is the Second Susceptibility Report prepared by our subcontractor WSP.

If you have questions regarding this report, please contact me.

Sincerely,
American Engineering Testing, Inc.

Jonathan Gabriel
Project Manager
218-216-9910
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Twin Ports Interchange
Vibration Susceptibility Report

Prepared For:

American Engineering Testing, Inc.

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St. Paul, MN 55114

Prepared By:

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Minneapolis, MN 55402

Date:

January 6, 2020

EXECUTIVE SUMMARY

This report documents a vibration susceptibility assessment for structures adjacent to the Twin Ports Interchange project in Duluth, Minnesota. This study represents an assessment of the potential for vibration levels generated by pile driving and blasting to cause disruption at structures within 300-feet of project pile driving locations. This report expands on the previously submitted Initial Vibration Assessment (9/25/19) by incorporating more detailed information on construction activities, soil types, and structure conditions from the pre-construction condition survey (PCCS) effort and establishes recommended vibration criteria for each structure to limit potential damage during construction.

The results of this vibration assessment show the following:

- PCCSs were completed for 46 of the 90 structures within 300-feet of project pile driving by the time of this report. Based on the structural conditions documented during the PCCS, all but three of the structures were rated as having Low susceptibility to cracking from vibration. Structures 16, 73, and 75 were rated as having Medium susceptibility to cracking from vibration. No structures with High susceptibility to cracking from vibration were identified in the study area.
- Based on the age, construction type, and condition of the structures, the recommended vibration damage threshold criteria for all structures is 0.5 in/sec peak particle velocity (PPV) for impact pile driving, 0.3 in/sec PPV for vibratory pile driving, and 2.0 in/sec PPV for blasting. The criteria apply at the exterior foundation of the structure in the vertical direction.
- Impact pile driving is predicted to generate vibration that exceeds damage criteria at:
    - Structure 70 (2023 W 1st Street): The predicted vibration value of 4.71 in/sec PPV is expected to significantly exceed the damage criterion due to impact pile driving occurring within 10-feet of the structure. Based on the magnitude of the predicted exceedance, vibration from impact pile driving is likely to cause cosmetic damage and could potentially cause structural damage at this location.
    - Structures 14 (2202 W 1st Street), 17 (2203 W 1st Street), 29 (2116 and 2122 W 2nd Street), and 85 (2125 W Superior Street): The predicted vibration values of 0.50 – 0.82 in/sec PPV are expected to exceed the damage criterion due to impact pile driving occurring within 65-feet of the structures. Based on the predicted exceedance, vibration from impact pile driving could potentially cause cosmetic damage at these locations.
- Other than at the structures listed above, which are also summarized in **Table 4**, impact pile driving is not expected to generate vibration that exceeds the damage criteria selected in this study. Similarly, vibratory pile driving and blasting are not expected to generate vibration that exceeds damage criteria at any structure location.
- Vibration from impact and vibratory pile driving is predicted to be perceived by humans as "severe" at Structure 70 and "distinctly to strongly perceptible" at several other structures in the project area (see **Table B-1**). While vibration is not expected to potentially cause damage at locations other than noted above, the perception of excessive vibration could cause annoyance

to the occupants of buildings, potential complaints, or for the occupants to believe their buildings are being damaged.

Based on the results of this assessment, it is recommended that:

- The Special Provisions should incorporate vibration damage criteria of 0.5 in/sec PPV for impact pile driving, 0.3 in/sec PPV for vibratory pile driving, and 2.0 in/sec PPV for blasting. The criteria apply at the exterior foundation of the structure in the vertical direction.
- Vibration should be monitored using approved seismographs at the exterior of Structures 14, 17, 29, 70, and 85 (see **Table 4**) when pile driving is occurring in proximity to those structures. If desired by MnDOT, continuous vibration monitoring at the single nearest structure to current pile driving activities could also be completed.
- If blasting is required, vibration should be monitored using approved seismographs at the exterior of Structure 9 (2220 W Michigan Avenue), or the nearest structure to blasting.
- Alternative construction methods to impact pile driving, or other vibration mitigation measures, should be considered to reduce the vibration level to which Structure 70 (2023 W 1st Street) may be exposed.

The following report contains more detailed information supporting these conclusions, recommendations for vibration monitoring equipment, and initial options to consider for vibration mitigation measures.

PROJECT DESCRIPTION

The Minnesota Department of Transportation's (MnDOT) Twin Ports Interchange project is located at the junction of I-35, I-535, and TH 53 in the Lincoln Park neighborhood of Duluth, MN. The project will replace the existing interchange with new roadways, ramps, and bridges. Other components of the project include the reconstruction of the interchange of I-535 and Garfield Avenue and the reconstruction of TH 53 from I-35 to approximately 3rd Street.

Construction of the project will require the use of typical construction equipment that has the potential to produce moderate to high levels of vibration such as impact pile drivers, vibratory pile drivers, blasting and vibratory compactors. Pile driving will occur at proposed bridge piers, abutments, and retaining walls. Based on project plans, blasting may potentially be needed at the inlet of Miller Creek for culvert construction. The locations of pile driving and blasting assumed for this study are shown in **Figures A-1 thru A-7** along with the receptor structures where vibration levels were assessed.

VIBRATION BACKGROUND AND CRITERIA

The MnDOT Geotechnical Manual (2017) references vibration criteria from two sources: the California Department of Transportation (CALTRANS) Transportation and Construction Vibration Guidance Manual (CALTRANS, 2013) for pile driving, and the US Bureau of Mines Report of Investigations 8507 (USBM, RI8507, 1980) for blasting.

The first set of CALTRANS criteria are specific peak particle velocity (PPV) vibration values, expressed in inches/second, for the threshold of potential damage from both transient sources (such as impact pile driving) and continuous sources (such as vibratory pile driving). Particle velocity is how fast a point moves from its rest state as the vibration wave passes by. The PPV is the highest or peak amplitude of the particle velocity (absolute value) and is measured as quickly as the instrumentation can respond (i.e. specifically not a root-mean-square, time-weighted, or average measured level).

PPV limits are well suited for evaluating potential damage to buildings caused by transient or impulsive types of vibration. PPV criteria limits should be viewed as guidelines for anticipating levels at which vibration damages could reasonably be expected to occur. The PPV criteria are intended to indicate the potential for vibration to cause cosmetic damage to a structure such as cracking plaster and misaligned window frame. Exceedance of a predicted or measured PPV value, however, does not necessarily mean that damage will occur instantly. This is because the criteria limits are slightly conservative, and thus have an inherent factor of safety built into them that considers the fact that construction materials and structural conditions vary between different building types. PPV criteria apply at the exterior ground surface adjacent to the structure and would be defined and measured in the vertical direction because it is the direction in the ground with the most freedom of motion.

The CALTRANS damage criteria for each type of vibration source also vary based on the sensitivity, or vulnerability, of the structure type to vibration. **Table 1** indicates the PPV criteria for several classes of building structures. Based on the age, construction type, and condition of the structures, all structures in the study area have been grouped into the "Older residential structures" class for the purposes of establishing vibration criteria.

Table 1: Vibration Damage Potential Threshold Criteria (CALTRANS)

Structure and Condition	Maximum PPV (in/sec)	
	Transient Sources	Continuous/Frequent Intermittent Sources
Extremely fragile historic buildings, ruins, ancient monuments	0.12	0.08
Fragile Buildings	0.2	0.1
Historic and some old buildings	0.5	0.25
Older residential structures	0.5	0.3
New residential structures	1.0	0.5
Modern industrial/commercial buildings	2.0	0.5

The second set of CALTRANS criteria shown in **Table 2** are PPV vibration values for potential human annoyance from both transient sources (such as impact pile driving) and continuous sources (such as vibratory pile driving). Humans can perceive vibration well before it is strong enough to potentially cause structural damage. When someone perceives vibration within their house it can either cause annoyance or the perception that damage is occurring and this criteria is intended to indicate when those reactions may occur.

Table 2: Vibration Annoyance Potential Criteria (CALTRANS)

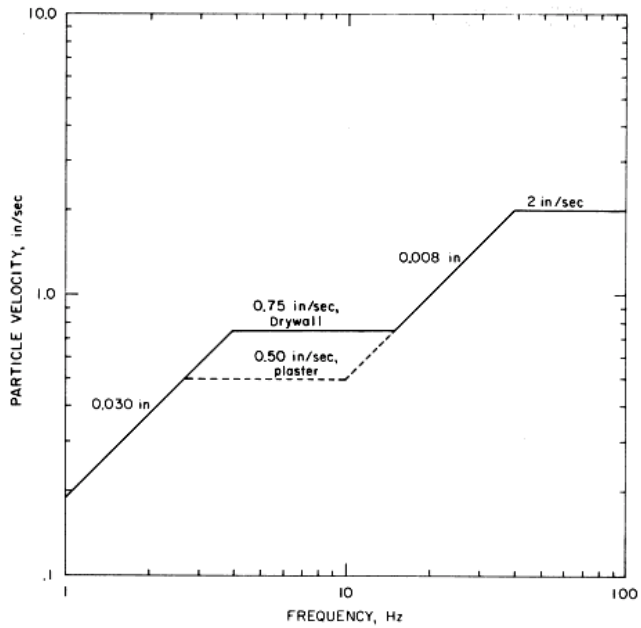
Human Response	Maximum PPV (in/sec)	
	Transient Sources	Continuous/Frequent Intermittent Sources
Barely perceptible	0.04	0.01
Distinctly perceptible	0.25	0.04
Strongly perceptible	0.9	0.10
Severe	2.0	0.40

USBM studies have been conducted for decades to assess the potential impact of blasting on neighboring facilities, primarily one- to two-story residential wood-frame structures. USBM was originally tasked with assessing the impact of blast vibration from quarry and coal mine blasting. USBM RI8507 determined that, besides PPV, the frequency of vibration waves also affects the potential for damage to neighboring above-ground structures. These structures respond to vibration imposed at the base of the structures through racking (relative horizontal motion of the top of a structure relative to the bottom where the vibration is induced), midwall response (horizontal motion of walls between fixed points at floor and ceiling), and other modes. As such, the structure will typically amplify the input vibration if the frequency of such vibration matches or is close to the natural frequency within the structure, thus creating an amplifying effect called resonance.

Although USBM was not authorized to create regulations, their recommendations for vibration amplitude (PPV) as a function of frequency were presented in Appendix B of RI8507, shown in **Figure 1** below. These recommendations have been incorporated in regulations worldwide and used to assess vibration impact from blasting for this study. As discussed in **Appendix C**, at the short distances, such as those anticipated from blasting to the nearby structures, previous experience indicates that dominant frequencies will be above 40 Hz and that the 2.0 in/sec PPV criterion is appropriate for this

project. The 2.0 in/sec criterion is for threshold or cosmetic damage to residential structures with plaster or drywall surfaces on wood-frame construction. Commercial structures are typically more rigid, and thus less susceptible to the relative motions that would cause threshold damage.

Figure 1: USBM Recommended Blast Vibration Criteria



RECEPTOR LOCATIONS

The study area for this project was established by MnDOT as extending 300-feet from all pile driving locations to account for all potentially affected structures. Ninety (90) structures were identified within the study area to be included in the pre-construction surveys and assessed in the vibration susceptibility study. The structures include residential, commercial, mixed-use residential/commercial, and industrial land-uses. No structures with vibration-sensitive equipment or operations were identified within the study area. Receptor locations where vibration was assessed were placed on the corner of each structure nearest to the project as shown in **Figures A-1 thru A-7**.

PRE-CONSTRUCTION CONDITION SURVEYS AND SUSCEPTIBILITY RATINGS

Owners of each structure within the study area were contacted to arrange pre-construction condition surveys (PCCS). By the time of this report, surveys were completed for 46 of 90 structures. The PCCS documented the existing structural and cosmetic condition of each structure and rated how susceptible each structure may be to cosmetic cracking (threshold damage) caused by vibration from project construction activities. The three categories of susceptibility to vibration are described below.

- *High Susceptibility* – Structure has already experienced a significant amount of degradation of its primary structural on nonstructural system, and additional vibration may further degrade these elements and possibly result in injuries to persons in the building. This category includes structures with loose or unstable elements such as loose bricks or structurally cracked terracotta cornices. <u>None of the surveyed structures have a susceptibility rating of High.</u>

- *Medium Susceptibility* – Although some building deterioration has occurred prior to construction, the structure has not yet experienced a significant degradation of its primary structure or its nonstructural systems that would lead to further building degradation due to construction vibration. This category includes structures with bricks that may be loose and structures with small to moderate quantities of fragile, potentially unstable contents that may be damaged by construction vibrations. Three of the surveyed structures have a susceptibility rating of Medium. The three Medium susceptibility structures are:
    - Structure 16 (2205 W 1st Street) – substantial cracks and evidence of water damage on building interior and exterior; potential fragile/unstable contents such as loose or hanging drop ceiling panels.
    - Structure 73 (17 N 20th Avenue W) – large cracks, spalls, and sections of brick/masonry block missing on the building interior.
    - Structure 75 (2022 W 1st Street) – vertical cracking and step cracking throughout interior walls; cracked brick on all sides of building exterior.
- *Low Susceptibility* – Structures that are not expected to experience cosmetic cracking or damage to contents when subject to moderate levels of vibration, such as those permitted by the OSM vibration criteria. All but three of the surveyed structures (noted above) have a susceptibility rating of Low.

VIBRATION ASSESSMENT METHODOLOGY

PILE DRIVING

Project design files were reviewed to identify locations where impact and vibratory pile driving is required for project construction. The primary locations for impact pile driving are bridge footings, bridge abutments, and along retaining walls. The primary locations for vibratory pile driving are bridge footings and the Miller's Creek culvert. Impact and vibratory pile driving locations are shown in **Figures A-1 thru A-7**.

WSP has developed a calculation model that estimates vibration levels generated by various construction equipment (sources) at adjacent structures (receivers) using industry standard methods. The model predicts vibration levels by using a reference PPV emission level for the type of equipment being assessed and then applying propagation factors to account for the source to receiver distance and the soil type along the propagation path. The model output is the estimated PPV vibration value for each specific source/receiver combination.

The Federal Transit Administration (FTA) Transit Noise and Vibration Impact Assessment Manual (FTA, 2018) includes reference peak particle velocity values for both vibratory ("sonic") and impact pile driving, as indicated in **Table 3**.

Table 3: Pile Driving Reference Peak Particle Velocity Values (FTA)

Equipment	Reference PPV at 25 ft (inch/sec)
Pile Driver (Impact – Upper Range)	1.518
Pile Driver (Impact – Typical)	0.644
Pile Driver (Vibratory – Upper Range)	0.734
Pile Driver (Vibratory – Typical)	0.170

A common and conservative practice is to use the Upper Range bounds for construction vibration assessments, roughly corresponding to a statistical 95% confidence level. In this way, there is an additional factor of safety that predicted vibration levels will not be exceeded in normal construction operations. The Upper Range reference PPV values shown in **Table 3** were used for vibration predictions in this study.

The soil characteristics along the path between the vibration source and the structure can significantly affect the vibration level to which the structure is exposed. Vibration propagates more efficiently through competent harder soil types such as dense sand, clay and rock compared to weaker or softer soils such as loose dirt and top soil.

A selection of the pre-construction soil borings taken for this project were reviewed to identify the soil types in the project area. From the review of the borings, soil types vary greatly throughout the project area but generally layers of stiff clay, clay sand, and loose sand were common within 25-feet of the ground surface. The most "conservative" soil type, or the soil type which allows for most efficient vibration propagation, was identified in the area near a boring location and used for the assessment of each receptor.

Using the nearest distance from the nearest pile driving locations to each structure and the identified soil type, PPV vibration velocity values were predicated at all structures within the study area.

BLASTING

Project design files were also reviewed to identify locations where blasting is proposed for project construction. The only potential location for blasting assessed in this study is near the Miller's Creek culvert, as shown in **Figure A-3** in **Appendix A** and **Figure C-1** in **Appendix C**.

The two nearest structures to the blasting location are Structures 8 (2228 W Michigan Avenue) and 9 (2220 W Michigan Avenue); thus, the potential vibration generated by blasting was estimated at those two structures. **Appendix C** provides a detailed discussion of the blasting vibration calculations.

VIBRATION PREDICTION RESULTS

Table B-1 in **Appendix B** shows the predicted PPV values from impact pile driving, vibratory pile driving, and blasting at all structures in the study area. **Table 4** presents a summary of structures potentially impacted by project-induced vibration.

IMPACT PILE DRIVING

The predicted impact pile driving PPV values in **Table B-1** have been evaluated relative to the damage criterion of 0.5 in/sec for "older residential structures" (**Table 1**) and annoyance potential criteria (**Table 2**).

Impact pile driving is predicted to generate vibration levels that exceed the potential damage criteria at:

- Structure 70 (2023 W 1st Street): The predicted vibration value of 4.71 in/sec PPV is expected to significantly exceed the damage criterion due to impact pile driving occurring within 10-feet of the structure. Based on the magnitude of the predicted exceedance, vibration from impact pile driving is likely to cause cosmetic damage and could potentially cause structural damage at this location. It is recommended that alternative construction methods to impact pile driving, or other vibration mitigation measures, should be considered to reduce the vibration levels to which this structure may be exposed.
- Structures 14 (2202 W 1st Street), 17 (2203 W 1st Street), 29 (2116 and 2122 W 2nd Street), and 85 (2125 W Superior Street): The predicted vibration values of 0.50 – 0.82 in/sec PPV are expected to exceed the damage criterion due to impact pile driving occurring within 65-feet of the structures. Based on the predicted exceedance, vibration from impact pile driving could potentially cause cosmetic damage at these locations.

Other than at the structures listed above, impact pile driving is not expected to generate vibration levels that exceed the vibration damage criteria.

Vibration from impact pile driving is expected to be perceived by humans as "severe" at Structure 70 and "distinctly perceptible" at Structures 69 (2019 W 1st Street), 81 (2118 W 1st Street), 85 (2125 W Superior Street), 86 (2122 W Superior Street), 88 (102 S 21st Avenue W), 90 (1910 W Michigan Street), and 95 (201 S 19th Avenue W). The perception of excessive vibration could cause annoyance to the occupants of these buildings, potential complaints, or for the occupants to believe their buildings are being damaged.

VIBRATORY PILE DRIVING

The predicted vibratory pile driving PPV vibration values in **Table B-1** have been evaluated relative to the vibration damage criterion of 0.3 in/sec for "older residential structures" (**Table 1**) and annoyance potential criteria (**Table 2**).

Vibratory pile driving is not expected to generate vibration that exceeds the damage criteria at any structure.

Vibration from vibratory pile driving is expected to be perceived by humans as "strongly perceptible" at Structures 86 (2122 W Superior Street) and 88 (102 S 21st Avenue W) and "distinctly perceptible" at

Structure 87 (2102 – 2112 W Superior Street). The perception of excessive vibration could cause annoyance to the occupants of these buildings, potential complaints, or for the occupants to believe their buildings are being damaged.

BLASTING

To determine the maximum anticipated vibration generated from blasting, the maximum explosive charge weight was estimated to be 9 pounds and the closest distance from blasting as 255 feet to Structure 9 (2220 W Michigan Street). Entering this information into **Equation 2** in **Appendix C** with the appropriate constants yields an estimated upper bound vibration value of 0.2 in/sec PPV. Because this value is well below the 2.0 in/sec PPV damage criterion and represents vibration at the nearest location to blasting, it can be concluded that blasting is not expected to generate vibration levels that exceed the damage criteria. Additional details on the blasting assessment are included in **Appendix C**.

Table 4: Vibration Prediction Results for Potentially Impacted Structures

Structure No.	Type / Name	Address	Vibration Susceptibility Rating[1]	Impact Pile Driving (Transient Source)				
				Distance (ft)	PPV (in/s)	PPV Criterion (in/s)	Complies or Exceeds Criterion	Human Response / Annoyance Potential
14	Commercial / Northern Door & Hardware	2202 W 1st Street	Low	60	0.54	0.5	Exceeds	Distinctly Perceptible
17	Commercial / Hybridge Imaging, Sagewood Gear	2203 W 1st Street	Low	64	0.50	0.5	Exceeds	Distinctly Perceptible
29	Residential / Easy Living Services	2116 and 2122 W 2nd Street	Low	51	0.66	0.5	Exceeds	Distinctly Perceptible
70	Commercial / Sid Harvey's	2023 W 1st Street	Low	10	4.71	0.5	Exceeds	Severe
85	Commercial / Duluth Children's Museum	2125 W Superior Street	Low	42	0.82	0.5	Exceeds	Distinctly Perceptible

[1] Pre-construction condition surveys were completed for all impacted structures identified in Table 4 by the time of this report.

VIBRATION MONITORING RECOMMENDATIONS

Monitoring of vibration levels during construction at critical structures is a key component in minimizing the risk for potential damages to the structures.

It is recommended that project-generated vibration should be monitored at the exterior of Structures 14, 17, 29, 70, and 85 (**Table 4**) when pile driving is occurring in proximity to those structures. If desired by MnDOT, continuous vibration monitoring at the single nearest structure to the current pile driving activities could also be completed.

If blasting is required, it is recommended that vibration be monitored at Structure 9, or the nearest structure to the blasting operations.

To measure vibration at the structures, seismographs, each of which complies with International Society of Explosives Engineers (ISEE) Guidelines for Field Practice, should be utilized. Location of the seismographs should consider ease of deployment and access, security of the instrument, and provisions for appropriate mounting. The seismograph geophones (vibration velocity sensors) should be attached securely to the ground or concrete, as appropriate. If mounted on concrete, it should be secured with anchor bolts such as Hilti RedHead or equivalent.

For pile driving measurements, records should be taken in a histogram/combination mode which assures that there is continuous recording, but that high level events are recorded as waveform events to distinguish pile driving vibration from spurious vibration such as spurious disturbances to the geophone.

If blasting is required, monitoring records should be taken in an appropriate triggered mode, and processed following each blast according to industry standard procedures found in the ISEE Guidelines. Determination of compliance or exceedance with the criteria should be assessed. If readings approach the recommended criterion limit, evaluation of blasting techniques should be taken and mitigation steps should be proposed.

VIBRATION MITIGATION OPTIONS

Excessive vibration generated from construction activities can be attenuated or mitigated in a number of manners, each of which requiring additional study to evaluate feasibility, effectiveness and potential cost. The following vibration mitigation measures are provided here for consideration and awareness only; they are not being specifically recommended for any particular receptor evaluated in this study.

In general, vibration controls are most effective if they can be applied to the source of the vibration, thus preventing the unwanted vibration from being generated in the first place. Vibration reduction measures applied along the pathway through which vibration travels can also be effective providing ground space and depth allow for implementation. Lastly, vibration mitigation measures applied directly at the receptor structure can also be effective particularly when other abatement options are not available. Examples of vibration mitigation options for construction pile driving and blasting could include:

- Ensure that a pre-construction survey, complete with pictures and videos, is performed in any/all receptors potentially at risk for damages. Note that pre-construction condition surveys were completed at all the structures listed in **Table 4** by the time of this report.

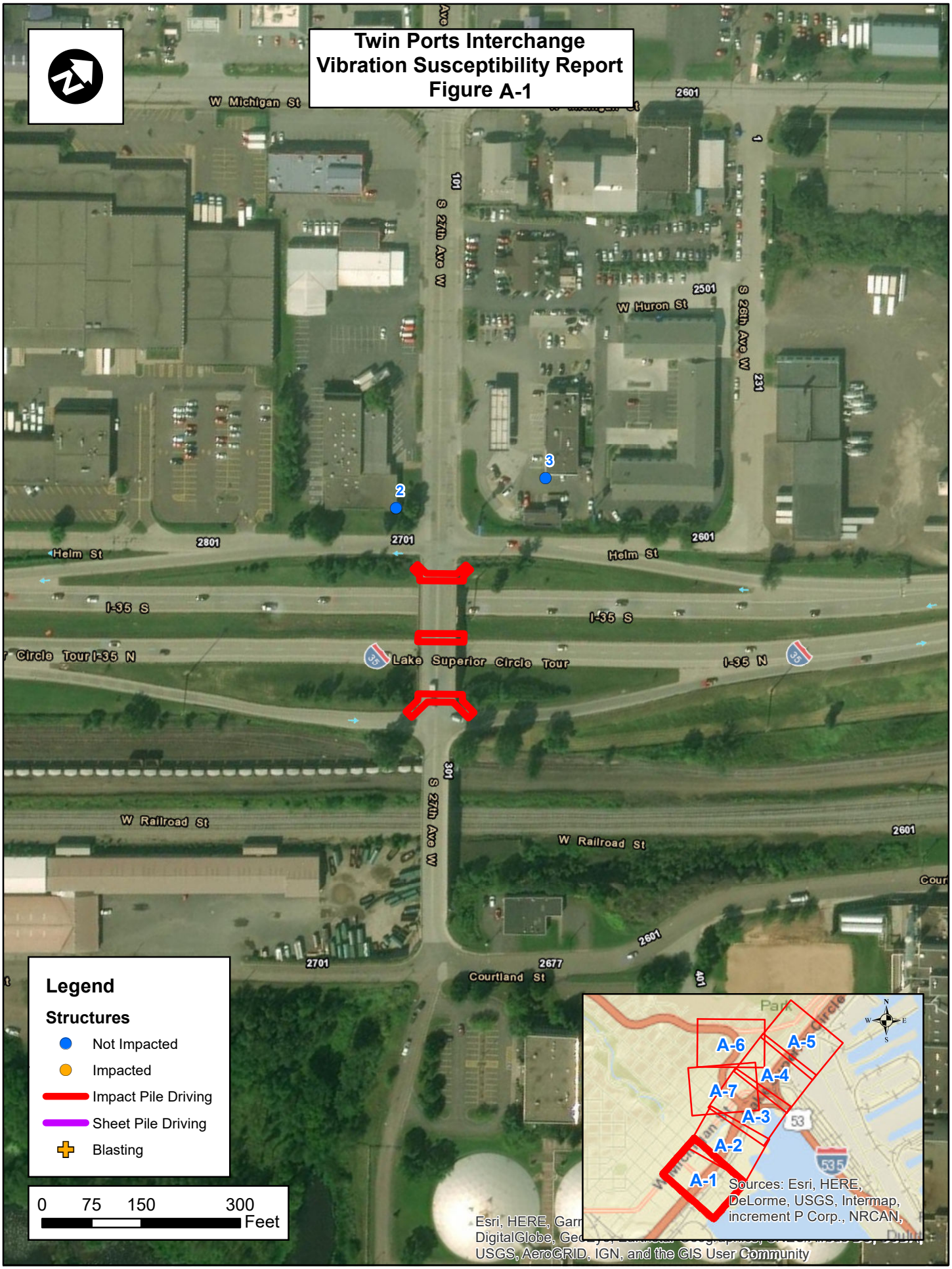
- Use a smaller or alternative method for pile driving such as hydraulic push piles.
- Use a vibratory pile driver for all piles because it generates lower PPV levels than an impact driver.
- Pre-trench or auger drill the pile hole except for the last portion for setting the pile firmly.
- Use drilled pile concrete caissons instead of piles and a pile driver.
- Dig a temporary underground trench between the source and the receptor to decouple the vibration pathway.
- Reinforce and strengthen the receptor structure by injection grouting its foundation area.
- Relocate the receptor by purchasing the property.

CONCLUSIONS

This vibration susceptibility study has assessed the potential for damage and human annoyance due to vibration produced from construction activities associated with the Twin Port Interchange project. Several structures near the project are expected to be exposed to vibration levels from impact pile driving that exceed recommended damage threshold criteria, and thus warrant vibration monitoring during project construction. Generic construction vibration mitigation methods are also provided for initial consideration.

APPENDIX A

FIGURES


Twin Ports Interchange
Vibration Susceptibility Report
Figure A-1
W Michigan St
S 27th Ave W
W Huron St
S 26th Ave W
Helm St
I-35 S
I-35 N
Lake Superior Circle Tour
W Railroad St
Courtland St
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Impacted
Impact Pile Driving
Sheet Pile Driving
Blasting
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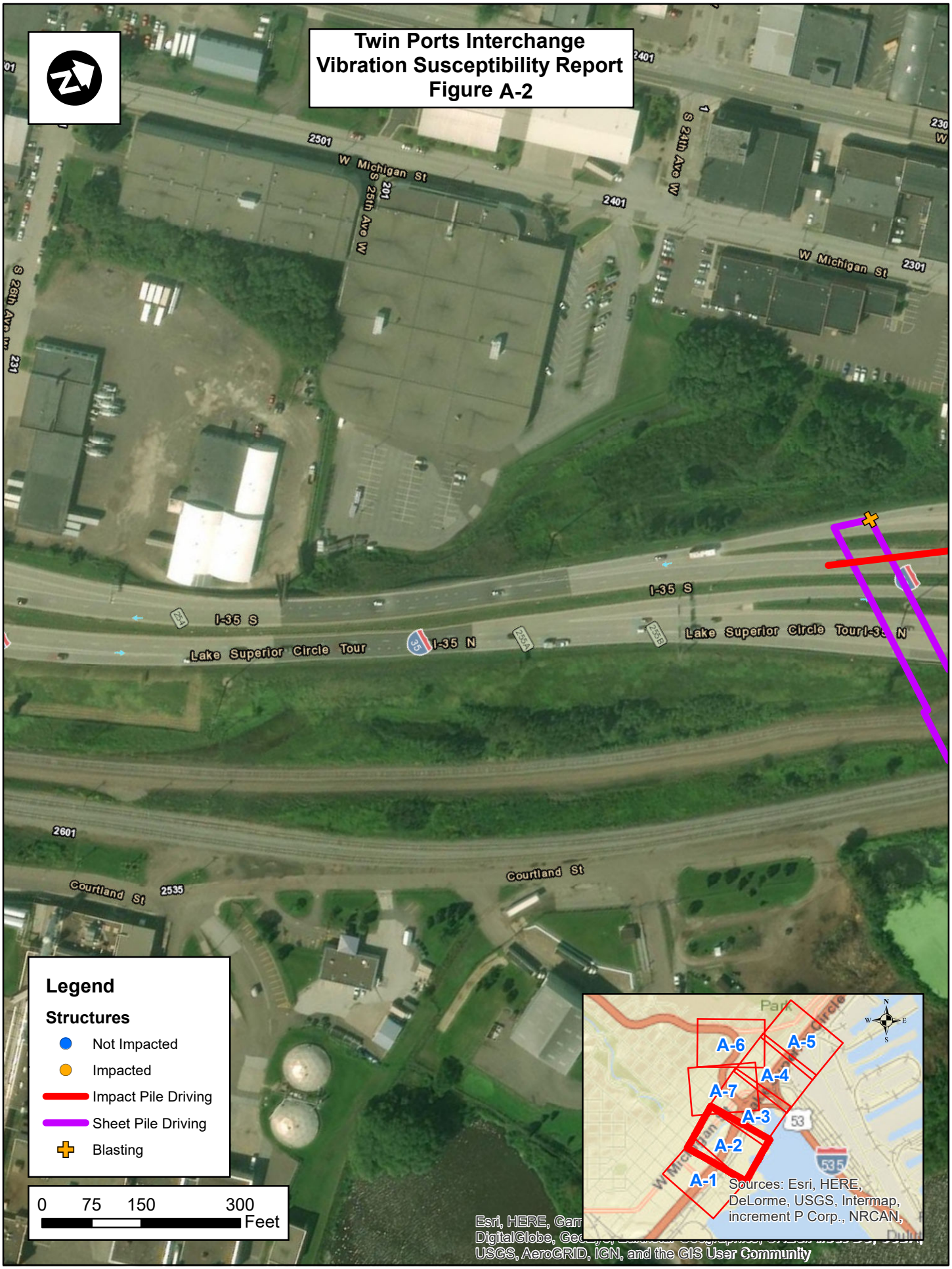
Twin Ports Interchange
Vibration Susceptibility Report
Figure A-2
W Michigan St
S 25th Ave W
S 24th Ave W
I-35 S
I-35 N
Lake Superior Circle Tour
Courtland St
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Structures
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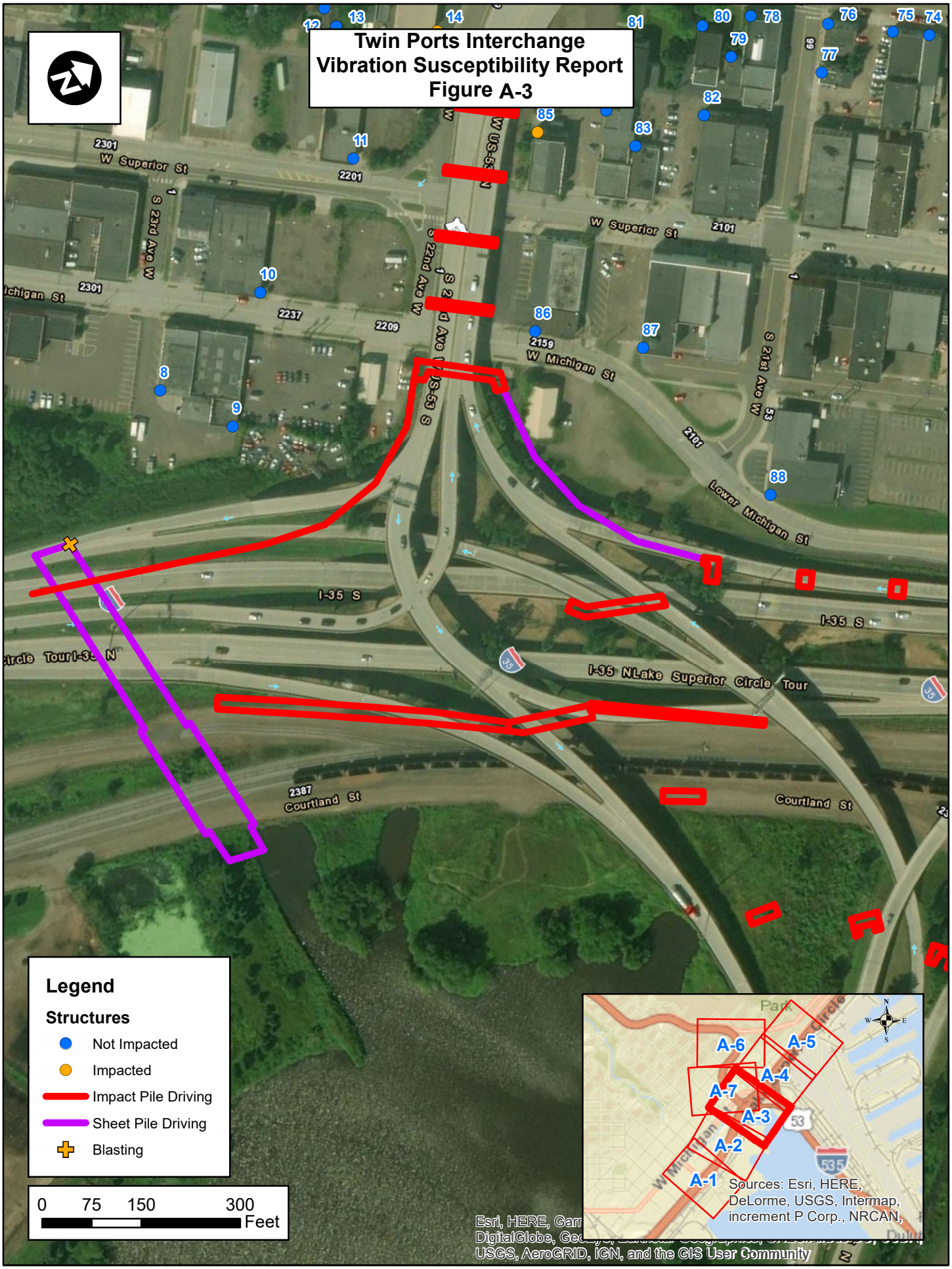
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN,
USGS, AeroGRID, IGN, and the GIS User Community


Twin Ports Interchange
Vibration Susceptibility Report
Figure A-3
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Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN,
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Twin Ports Interchange
Vibration Susceptibility Report
Figure A-4
75
74
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N 20th Ave W
N 19th Ave W
W Superior St
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Lower Michigan St
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Lake Superior Circle Tour
Burlington Northern Santa Fe
Courtland St
North Shore Scenic
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Twin Ports Interchange
Vibration Susceptibility Report
Figure A-5
Piedmont Ave
N 16th Ave W
W Superior St
S 18th Ave W
W Michigan St
Lower Michigan St
Canal Ave
I-35 S
I-35 N
Lake Superior Circle Tour
North Shore Scenic
W Railroad St
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94
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Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN,
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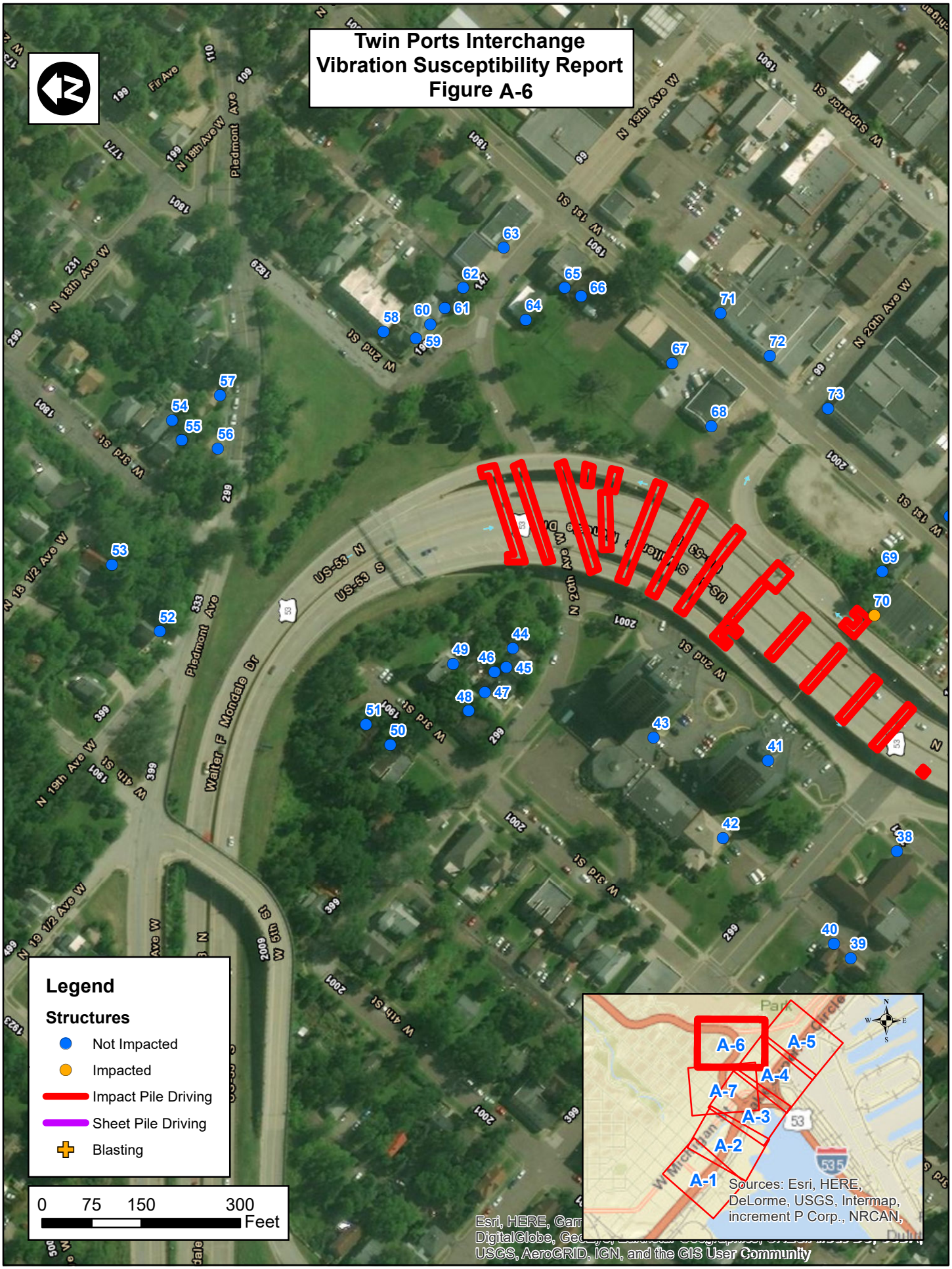
Twin Ports Interchange
Vibration Susceptibility Report
Figure A-6
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Structures
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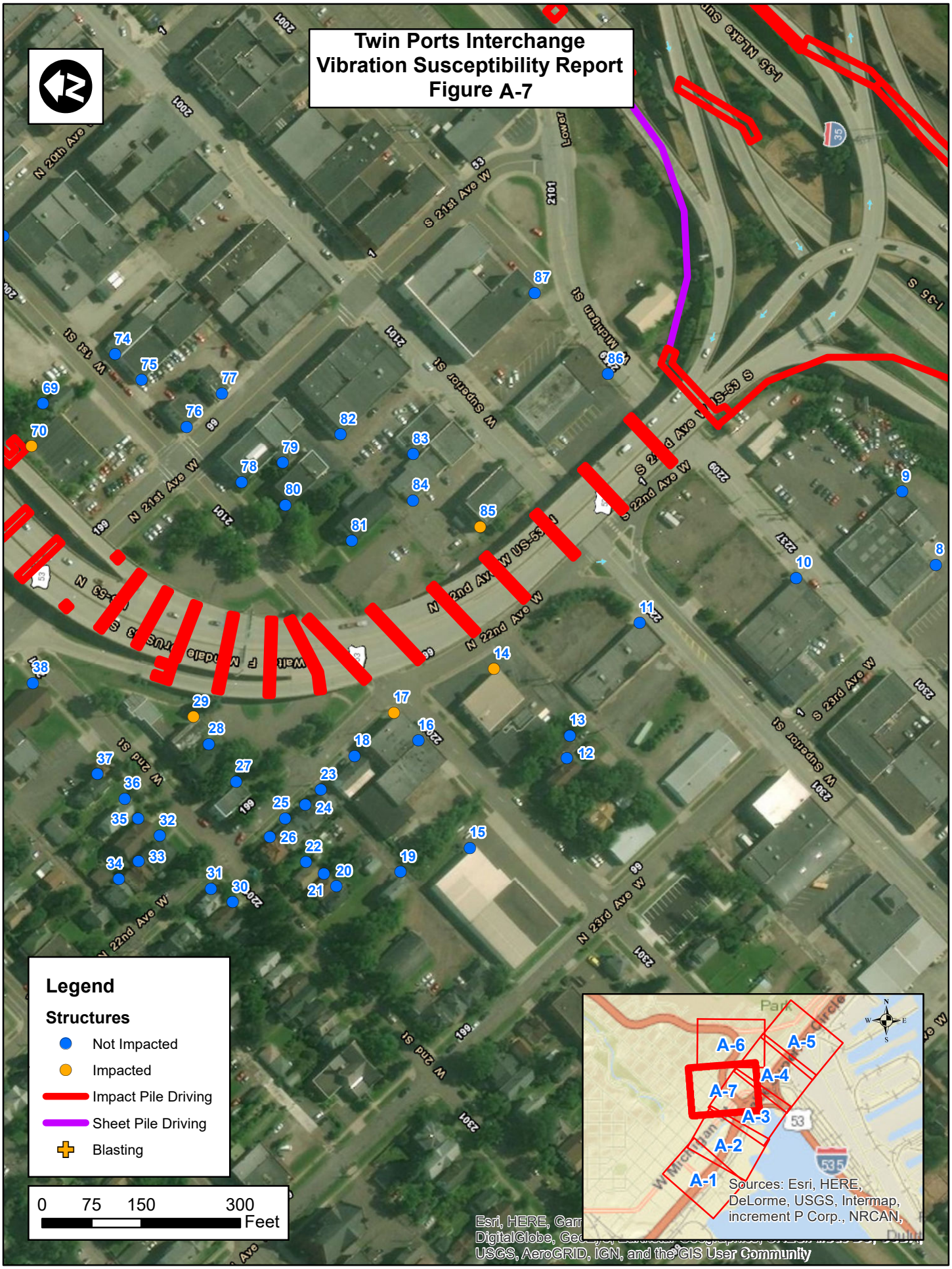
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN,
Esri, HERE, Garmin, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Walter F Mondale Dr
Piedmont Ave
N 18th Ave W
N 19th Ave W
N 20th Ave W
W 1st St
W 2nd St
W 3rd St
W 4th St
W 5th St
W Superior St
US-53 N
US-53 S
Fir Ave


Twin Ports Interchange
Vibration Susceptibility Report
Figure A-7
Legend
Structures
Not Impacted
Impacted
Impact Pile Driving
Sheet Pile Driving
Blasting
0 75 150 300
Feet
A-1
A-2
A-3
A-4
A-5
A-6
A-7
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN,
USGS, AeroGRID, IGN, and the GIS User Community

APPENDIX B

TABLE B-1: VIBRATION PREDICTION RESULTS[2]

Structure No.	Type	Address	Vibration Susceptibility Rating[3]	Impact Pile Driving (Transient Source)					Vibratory Pile Driving (Continuous Source)					Blasting			
				Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies or Exceeds Criterion	Human Response / Annoyance Potential	Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies with Criterion	Human Response / Annoyance Potential	Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies with Criterion
2	Commercial	215 S 27th Ave W	Low	91	0.33	0.5	Complies	Distinctly Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
3	Commercial	210 S 27th Ave W		179	0.15	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
8	Commercial	2228 W Michigan St	Low	260	0.09	0.5	Complies	Barely Perceptible	270	0.04	0.3	Complies	Distinctly Perceptible	270	0.2	2.0	Complies
9	Commercial	2220 W Michigan St		185	0.14	0.5	Complies	Barely Perceptible	305	0.04	0.3	Complies	Distinctly Perceptible	255	0.2	2.0	Complies
10	Commercial	2224 W Superior St	Low	254	0.10	0.5	Complies	Barely Perceptible	396	0.03	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
11	Commercial	2215 W Superior St		140	0.20	0.5	Complies	Barely Perceptible	416	0.03	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
12	Residential	2220 W 1st St		234	0.11	0.5	Complies	Barely Perceptible	637	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
13	Residential	2218 W 1st St		211	0.12	0.5	Complies	Barely Perceptible	604	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
14	Commercial	2202 W 1st St	Low	60	0.54	0.5	**Exceeds**	Distinctly Perceptible	551	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
15	Commercial	2231 W 1st St	Low	291	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
16	Commercial	2205 W 1st St	Medium	117	0.24	0.5	Complies	Barely Perceptible	703	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
17	Commercial	2203 W 1st St	Low	64	0.50	0.5	**Exceeds**	Distinctly Perceptible	690	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
18	Residential	113 - 115 N 22nd Ave W	Low	108	0.27	0.5	Complies	Distinctly Perceptible	778	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
19	Residential	2216 W 2nd St		292	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
20	Residential	2212 W 2nd St		295	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
21	Residential	2210 W 2nd St		275	0.09	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
22	Residential	2208 W 2nd St	Low	257	0.10	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
23	Residential	117 N 22nd Ave W		147	0.19	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
24	Residential	119 N 22nd Ave W	Low	171	0.16	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
25	Residential	121 N 22nd Ave W	Low	187	0.14	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
26	Residential	123 N 22nd Ave W		214	0.12	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
27	Residential	2132 W 2nd St	Low	137	0.20	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
28	Residential - duplex	2126 W 2nd St	Low	81	0.38	0.5	Complies	Distinctly Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
29	Residential	2116 and 2122 W 2nd St	Low	51	0.66	0.5	**Exceeds**	Distinctly Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
30	Residential	2203 W 2nd St		317	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
31	Residential	2201 W 2nd St	Low	298	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
32	Residential - duplex	2131 W 2nd St		232	0.11	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies

[2] Red text indicates receptors where vibration is predicted to exceed damage criteria.
[3] Vibration susceptibility rating is based on information from the pre-construction condition surveys (PCCS) of structures. A rating is only shown for the structures where the PCCS was completed by the time of this report submittal.

Structure No.	Type	Address	Vibration Susceptibility Rating[3]	Impact Pile Driving (Transient Source)					Vibratory Pile Driving (Continuous Source)					Blasting			
				Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies or Exceeds Criterion	Human Response / Annoyance Potential	Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies with Criterion	Human Response / Annoyance Potential	Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies with Criterion
33	Residential	212 N 22nd Ave W		274	0.09	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
34	Residential	214 N 22nd Ave W		306	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
35	Residential - duplex	2125-2127 W 2nd St	Low	211	0.12	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
36	Residential - duplex	2123 W 2nd St		188	0.14	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
37	Residential - church	2119 W 2nd St		168	0.16	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
38	Commercial	2101 W 2nd St	Low	120	0.24	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
39	Residential - 4 unit	2112 W 3rd St	Low	297	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
40	Residential	2106 W 3rd St		288	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
41	Residential - 14 story	2021 W 2nd St	Low	121	0.24	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
42	Commercial	2024 W 3rd St	Low	252	0.10	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
43	Commercial	2014 W 3rd St	Low	174	0.15	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
44	Residential	218 N 20th Ave W		131	0.21	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
45	Residential	222 N 20th Ave W	Low	159	0.16	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
46	Residential	224 N 20th Ave W		168	0.15	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
47	Residential	226 N 20th Ave W	Low	199	0.12	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
48	Residential - duplex	230 N 20th Ave W		233	0.10	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
49	Residential - triplex	1924 W 3rd St	Low	174	0.15	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
50	Residential - triplex	1927 W 3rd St		329	0.07	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
51	Residential	1921 W 3rd St		326	0.07	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
52	Residential	314 N 19th Ave W		536	0.04	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
53	Residential	301 N 18H Ave W		576	0.03	0.5	Complies	Imperceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
54	Residential	1820 W 3rd St		472	0.04	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
55	Residential - duplex	1822 W 3rd St		453	0.05	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
56	Residential - triplex	226 Piedmont Ave	Low	398	0.05	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
57	Residential	220 Piedmont Ave		409	0.05	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
58	Residential	1826 W 2nd St	Low	253	0.09	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
59	Residential	130 N 19th Ave W		220	0.11	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
60	Residential - duplex	128 N 19th Ave W	Low	231	0.10	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
61	Residential - duplex	126 N 19th Ave W		249	0.09	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
62	Residential - duplex	122 N 19th Ave W		273	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
63	Commercial	1831 W 1st St		326	0.07	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
64	Residential	115 N 19th Ave W	Low	216	0.11	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
65	Residential - multi 8 unit	1901 W 1st St		263	0.09	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
66	Residential	1905 W 1st St	Low	252	0.09	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
67	Commercial	1915 W 1st St		181	0.14	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies

Structure No.	Type	Address	Vibration Susceptibility Rating[3]	Impact Pile Driving (Transient Source)					Vibratory Pile Driving (Continuous Source)					Blasting			
				Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies or Exceeds Criterion	Human Response / Annoyance Potential	Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies with Criterion	Human Response / Annoyance Potential	Distance (ft)	PPV (in/s)	Maximum PPV Criterion (in/s)	Complies with Criterion
68	Commercial	1925 W 1st St	Low	114	0.24	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
69	Residential	2019 W 1st St		67	0.47	0.5	Complies	Distinctly Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
70	Commercial	2023 W 1st St	Low	10	4.71	0.5	**Exceeds**	Severe	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
71	Commercial	1926 W 1st St		273	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
72	Commercial	1928 W 1st St		245	0.10	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
73	Commercial	17 N 20th Ave W	Medium	228	0.11	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
74	Commercial	2020 W 1st St	Low	197	0.13	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
75	Commercial	2022 W 1st St	Medium	204	0.13	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
76	Commercial	32 N 21st Ave W		217	0.12	0.5	Complies	Barely Perceptible	740	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
77	Commercial	24 N 21st Ave W		288	0.08	0.5	Complies	Barely Perceptible	680	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
78	Commercial	27 N 21st Ave W		196	0.13	0.5	Complies	Barely Perceptible	678	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
79	Residential and Commercial	21 & 31 N 21st Ave W	Low	235	0.11	0.5	Complies	Barely Perceptible	610	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
80	Commercial	2110 W 1st St	Low	171	0.16	0.5	Complies	Barely Perceptible	627	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
81	Commercial	2118 W 1st St	Low	104	0.28	0.5	Complies	Distinctly Perceptible	561	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
82	Commercial	2101 & 2105 W Superior St	Low	264	0.09	0.5	Complies	Barely Perceptible	514	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
83	Commercial	2113 W Superior St	Low	188	0.14	0.5	Complies	Barely Perceptible	419	0.03	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
84	Commercial	2117 W Superior St	Low	131	0.21	0.5	Complies	Barely Perceptible	450	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
85	Commercial	2125 W Superior St	Low	42	0.82	0.5	**Exceeds**	Distinctly Perceptible	392	0.03	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
86	Commercial	2122 W Superior St		72	0.42	0.5	Complies	Distinctly Perceptible	100	0.14	0.3	Complies	Strongly Perceptible	> 300	N/A	N/A	Complies
87	Commercial	2102-2112 W Superior St	Low	217	0.11	0.5	Complies	Barely Perceptible	218	0.05	0.3	Complies	Distinctly Perceptible	> 300	N/A	N/A	Complies
88	Commercial	102 S 21st Ave W		125	0.29	0.5	Complies	Distinctly Perceptible	144	0.12	0.3	Complies	Strongly Perceptible	> 300	N/A	N/A	Complies
89	Commercial	114 S 20th Ave W	Low	131	0.21	0.5	Complies	Barely Perceptible	576	0.02	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
90	Commercial	1910 W Michigan St	Low	88	0.34	0.5	Complies	Distinctly Perceptible	720	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
91	Commercial	1832 W Michigan St	Low	292	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
92	Commercial	1726 W Michigan St		243	0.07	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
93	Commercial	1532 W Michigan St	Low	280	0.06	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
94	Commercial	210 Garfield Ave		221	0.08	0.5	Complies	Barely Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies
95	Commercial	201 S 19th Ave W		97	0.32	0.5	Complies	Distinctly Perceptible	> 800	0.01	0.3	Complies	Barely Perceptible	> 300	N/A	N/A	Complies

APPENDIX C

ADDITIONAL BLASTING ASSESSMENT DETAILS

FREQUENCY CONSIDERATIONS AND RECOMMENDED CRITERIA

The criterion for vibration recommended in USBM RI 8507, which is shown in **Figure 1,** is dependent upon frequency. While frequency of vibration is strongly dependent upon the local geology, and less so upon blast design, the predominant factor influencing vibration frequency is distance. Vibration typically decreases in frequency with distance. High frequencies are attenuated, and low frequencies are amplified by the geologic path travelled.

At short distances such as those anticipated for the nearby structures, previous experience indicates that dominant frequencies will be above the 40 Hz threshold for the 2.0 in/sec criterion shown in **Figure 1**. At greater distances where low frequency vibration may be of concern, the amplitude will have attenuated to negligible levels. Therefore, the 2.0 in/sec criterion is considered to be appropriate for this project.

PREDICTION METHOD

The method to determine the likely vibration levels generated by blasting is based on USBM studies, where it's been demonstrated that there are two main equations that govern vibration amplitude or Peak Particle Velocity (PPV). In **Equation 1**, Scaled Distance (SD) is defined as:

$$SD = \frac{D}{\sqrt{W}} \qquad (1)$$

where D is the distance (in feet) from the blast to the measuring location, and W is the charge weight (in pounds) detonated per 8 millisecond delay interval. Since the 1950s blasts have been detonated with delay detonators (or blasting caps) that incorporate a delay element in the cap structure such that explosive-loaded boreholes are detonated in a predetermined sequence rather than all at once. The conventional electric or non-electric detonators are pyrotechnic, and the delay element is much like a black powder "fuse" within the cap container. More recently these have been superseded by electronic detonators, where the delay element is a miniature timer much like a digital watch. The electronic detonators are substantially more accurate, but the conventional detonators are still in general use.

Equation 2 incorporates the definition of Scaled Distance into a site-specific power-law equation that is the result of the Bureau's research as well as many subsequent on-site studies:

$$PPV = K * SD^{-B} \qquad (2)$$

where K and B are site specific constants developed during blast investigations. In green-site development, these constants are typically first determined during test blasts, and then refined during subsequent production blasting. Prior to the initiation of blasting, nominal values for the constants (for estimates of highest likely vibration) are based upon similar blasts conducted under comparable

conditions. This assessment followed guidance provided by the International Society of Explosives Engineers.

To determine likely vibration from construction blasting, the blasting procedures anticipated for the project must be considered. Blasts for typical construction excavation consist of an array of boreholes drilled in a regular pattern. After drilling is complete, the boreholes are loaded with detonators, primers and explosive. The detonators are manufactured with either constant or programmable millisecond delays, and they are connected in a sequence such that when the detonation sequence begins, the first holes to fire are adjacent to a free face. As detonation proceeds, the blasted rock creates a new "free face", reducing vibration and enhancing fragmentation. The sequence is initiated at one hole, and all the holes are then part of a single sequence.

MAXIMUM CHARGE WEIGHT PER DELAY CALCULATIONS

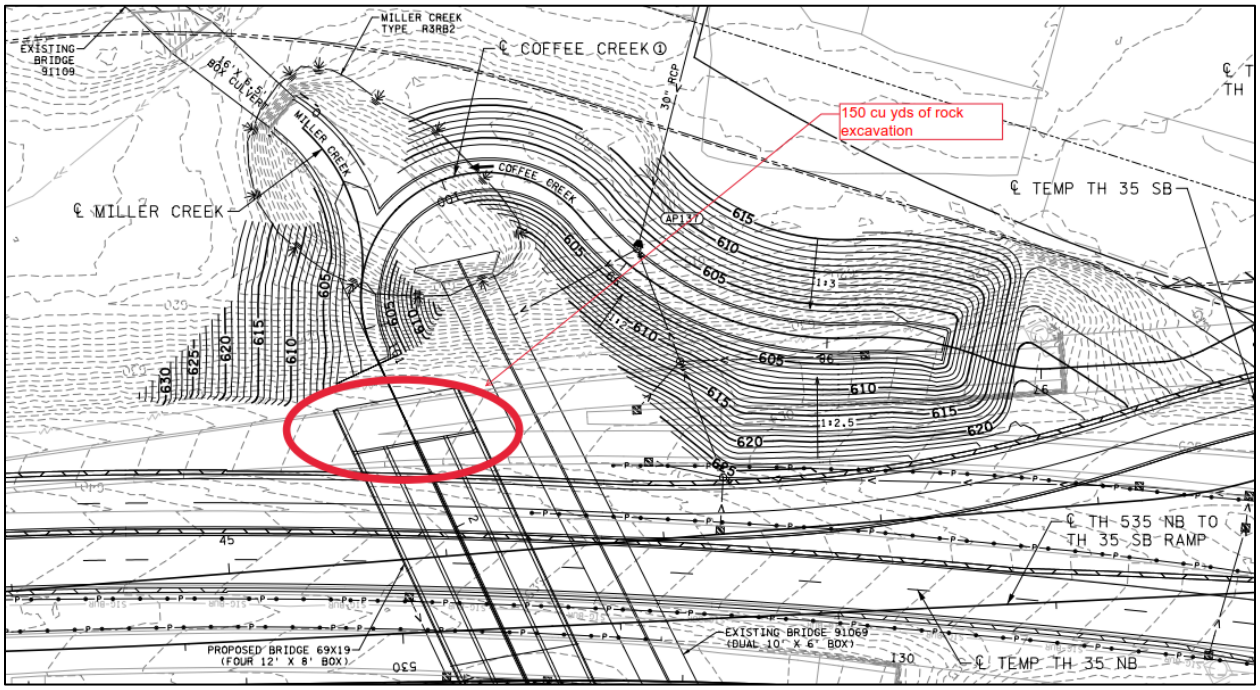
If blasting is necessary for this project, it has been assumed that industry-standard methods will be used to perform the blasting. Typically, basic information is provided prior to estimating vibration levels. To determine the charge weight per delay, the following information is needed:

- Borehole diameter, indicating the maximum diameter of explosive.
- Depth of excavation, indicating maximum length of borehole.
- Type of explosive, determining the explosive density.

This information was not available for this project, but a maximum charge weight can be inferred in the following way:

- Explosive Diameter
    1. Typically, an excavation project like this would use a maximum drilled borehole diameter of about 3 to 3.5 inches.
    2. Larger diameters (4 to 9 inches) are used in quarries, and much larger (10 to 18 inches) in surface coal mines.
    3. It is therefore considered that the maximum diameter borehole would be 3.5 inches.
    4. Thus, the largest cartridge explosive practically used would have a diameter of 3 inches.
- Depth of Excavation
    1. To determine the excavation depth, we used **Figure C-1** provided by MnDOT, which shows the size of the area of potential excavation, as well as the anticipated amount of rock to be excavated.

Figure C-1: Area and Location for Blast Excavation



2. The area of the proposed excavation wass calculated from **Figure C-1**: Approximately 1,322 square feet.
3. The amount of rock proposed to be excavated, also from **Figure C-1**: 150 cubic yards.
4. Dividing 2 by 1 (with the conversion factor 1 cu yd = 27 cu ft), results in an excavation depth of approximately 3 feet.
5. Generally, borehole drilling in an excavation like this is done about one foot below grade; conversely, about one foot of inert stemming material would be at the top of the borehole to contain explosive energy.
6. Therefore, it is assumed about 3 feet of explosive would be used <u>per borehole</u>.

- Type of explosive:
  1. A typical explosive used for construction excavation is Austin Powder Emulex 927.
  2. This explosive has a density of 1.17 g/cc, representative of many emulsion explosives.
  3. Packaging of the explosive in 3” diameter by 16” length has a weight of 4.55 pounds.
- Estimate of weight per charge:
  1. Explosive diameter 3” in 16” length → 4.55 pounds
  2. Charge length required ~36”
- **∴ Two sticks of explosive required per borehole, ~9 pounds**

PEAK LEVEL DETERMINATION

The specific details of the blasting that may be required for the project aren't known, but it is assumed that typical procedures will be used. Three data elements are necessary to determine the vibration estimates:

- Maximum Anticipated Charge Weight per delay.
- Distance of the structure locations from the blast.
- Appropriate constants to use in **Equation 2**.

As shown above, it was determined that the likely Charge Weight per Delay is 9 pounds.

The distance from blasting to the nearest structures was based on the blasting and receptor locations shown in F**igures C-1 and A-3.** The closest structures to potential blasting are Structures 8 and 9, as detailed in the following table.

Structure Number	Structure Type	Address	Name	Distance (ft)
8	Commercial	2228 W Michigan St	Bill's Muffler and Brake Service	270
9	Commercial	2220 W Michigan St	Johns Twin Ports Recycling	255

Distances to these structures from proposed blasting was measured using Google Earth calculations. These structures of concern are primarily engineered above-ground structures. As such, they are typically more resistant to vibration damage than the wood-frame residential structures studied in the USBM reports. However, though a criterion of 4 in/sec is sometimes applied to engineered structures, the recommended criteria in RI 8507 are typically applied to all above-ground structures.

Last, it was necessary to determine appropriate constants to use in **Equation 2**. The best reference for those constants is the International Society of Explosives Engineers (ISEE) Blasters' Handbook (Engineers, 2011) (18th Edition) Table 26.3, which is shown below. Based on the below table, the recommended constants for Upper Bound Construction Industry blasting to use in **Equation 2** are K= 242 and B= -1.6.

Entering this information into **Equation 2** with the appropriate constants yields an estimated upper bound vibration value of 0.2 in/sec PPV. Because this value is well below the 2.0 in/sec PPV damage criterion and represents vibration at the nearest location to blasting (Structure 9), it can be concluded that blasting is not expected to generate vibration levels that exceed the damage criteria.

Vibration Amplitude Equations For Various Blasting Industries				
Industry	**Metric Equations** mm/sec.	**U.S. Equations** in./sec.	**Confidence level**	**Source**
General	$PPV = 1{,}140(SD_2)^{-1.6}$	$PPV = 160(SD_2)^{-1.6}$	Best Fit	DuPont
Construction	$PPV = 173(SD_2)^{-1.6}$	$PPV = 24.2(SD_2)^{-1.6}$	Lower Bound	Oriard
Construction	$PPV = 1{,}730(SD_2)^{-1.6}$	$PPV = 242(SD_2)^{-1.6}$	Upper Bound	Oriard (2005)
Construction	$PPV = 4{,}320(SD_2)^{-1.6}$	$PPV = 605(SD_2)^{-1.6}$	Upper Bound - High Confinement	Oriard (2005)
Construction	$PPV = 53(SD_2)^{-1.09}$	$PPV = 5(SD_2)^{-1.09}$	Best Fit	USBM RI 8507
Quarries	$PPV = 1{,}090(SD_2)^{-1.82}$	$PPV = 182(SD_2)^{-1.82}$	Best Fit	USBM Bulletin 656
Coal Mines	$PPV = 905(SD_2)^{-1.52}$	$PPV = 119(SD_2)^{-1.52}$	Best Fit	USBM RI 8507
Coal Mines	$PPV = 3{,}330(SD_2)^{-1.52}$	$PPV = 438(SD_2)^{-1.52}$	Upper bound	USBM RI 8507
Coal - Low Frequency sites	$PPV = 1{,}252(SD_2)^{-1.31}$	$PPV = 138(SD_2)^{-1.31}$	Best Fit	USBM RI 9226

Table 26.3 - Vibration amplitude equations for various blasting industries.