Appendix Q Construction Vibration Assessment (May 2016)

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CONSTRUCTION VIBRATION ASSESSMENT
661 BEAR VALLEY TENTATIVE SUBDIVISION MAP
ESCONDIDO, CA

Submitted to:

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ISE Project #14-023

May 19, 2016

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INTRODUCTION AND DEFINITIONS

Existing Site Characterization

The proposed 661 Bear Valley Tentative Subdivision Map (APN's 237-131-01, 02) consists of approximately 40.9 gross acres, located in the North County Area of San Diego County in the City of Escondido, as shown in Figure 1 on the following page. Regional access to the site is obtained from Bear Valley Parkway as shown in Figure 2 on Page 3 of this report. Surrounding land uses consist of single-family residential lots, limited commercial uses, and undeveloped open space. These features, as well as the proposed site plan configuration, can be seen in Figure 3 on Page 4 of this report.

The project site resides as a fully disturbed land use (i.e., a past extractive/mining use), and currently has one single-family residential structure onsite. Elevations across the property range from approximately 530 feet to 675 feet above mean sea level (MSL).

Project Description

The 661 Bear Valley Tentative Subdivision Map would construct fifty five (55), approximately 10,000 square-foot, single family residential lots as shown in Figures 4 and 5 starting on Page 5 of this report. The project would also include necessary roadway and drainage improvements as well as the dedication of approximately 1.2 acres for improvements to Bear Valley Parkway.

Ground Vibration Definitions and Theory

Vibration is generally defined as any oscillatory motion induced in a structure or mechanical device as a direct result of some type of input excitation. The object of interest typically has sufficient inertia 'm' so that by Newton's first law of motion, its rest state is one of zero vibration with velocity 'v' equal to zero. Input excitation, in the form of an applied external force 'F' is the mechanism required to start some type of vibratory response. Mathematically, this governing equation can be expressed in the following form for an object's rest state as,

$$\frac{d}{dt}(mv) = \sum_{Ext} F = 0$$

Once an object begins to respond to an applied force excitation, its natural tendency is to vibrate as a linear combination of its natural frequencies. A 'natural frequency' is defined as the frequency at which an object will tend to vibrate if set into motion and allowed to move freely. Any continuous system of particles will have an infinite number of natural frequencies, with each one adding to the overall response in a series of ever-decreasing contributions.

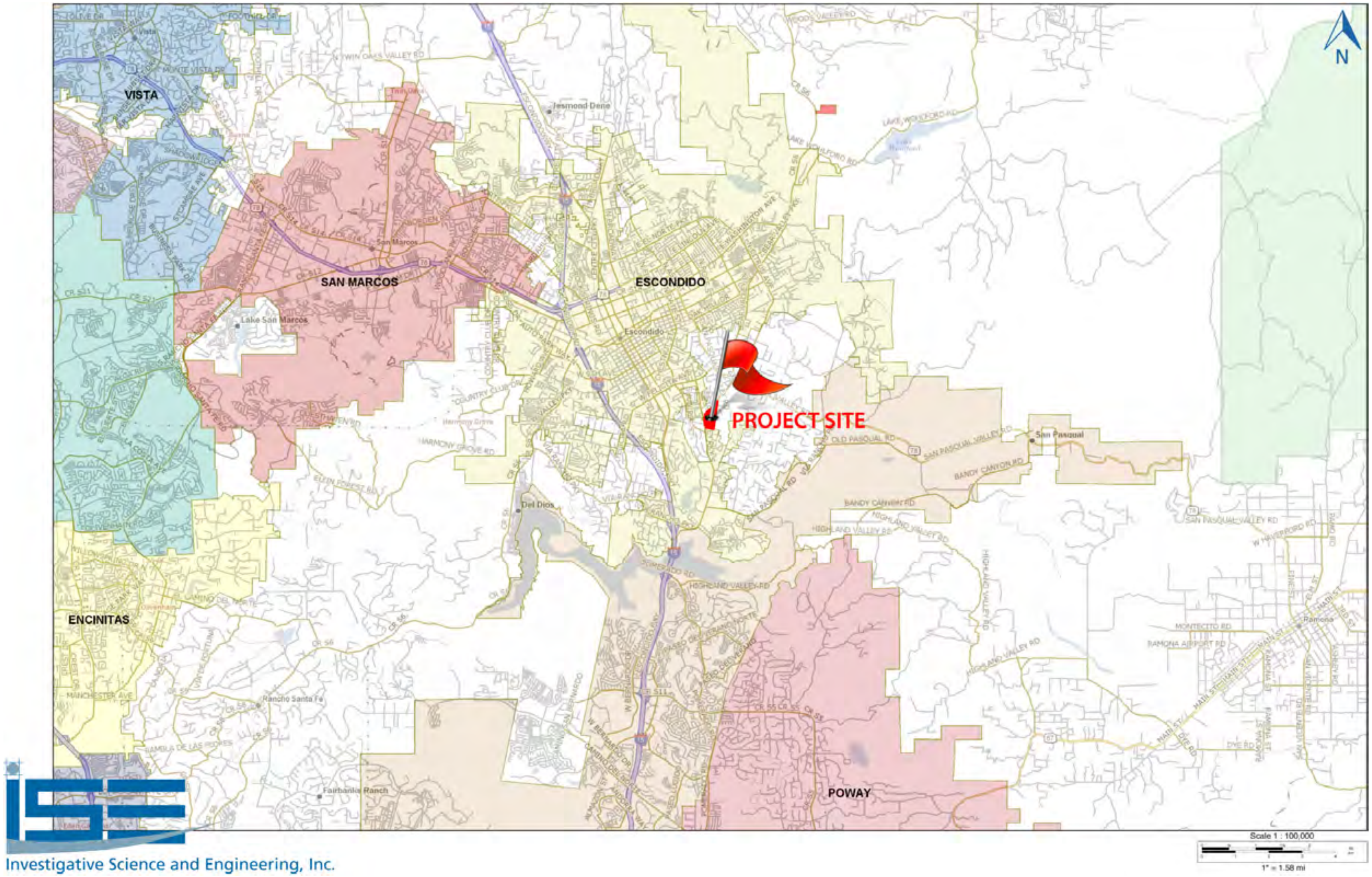

FIGURE 1: Project Study Area Vicinity Map (ISE 12/14)

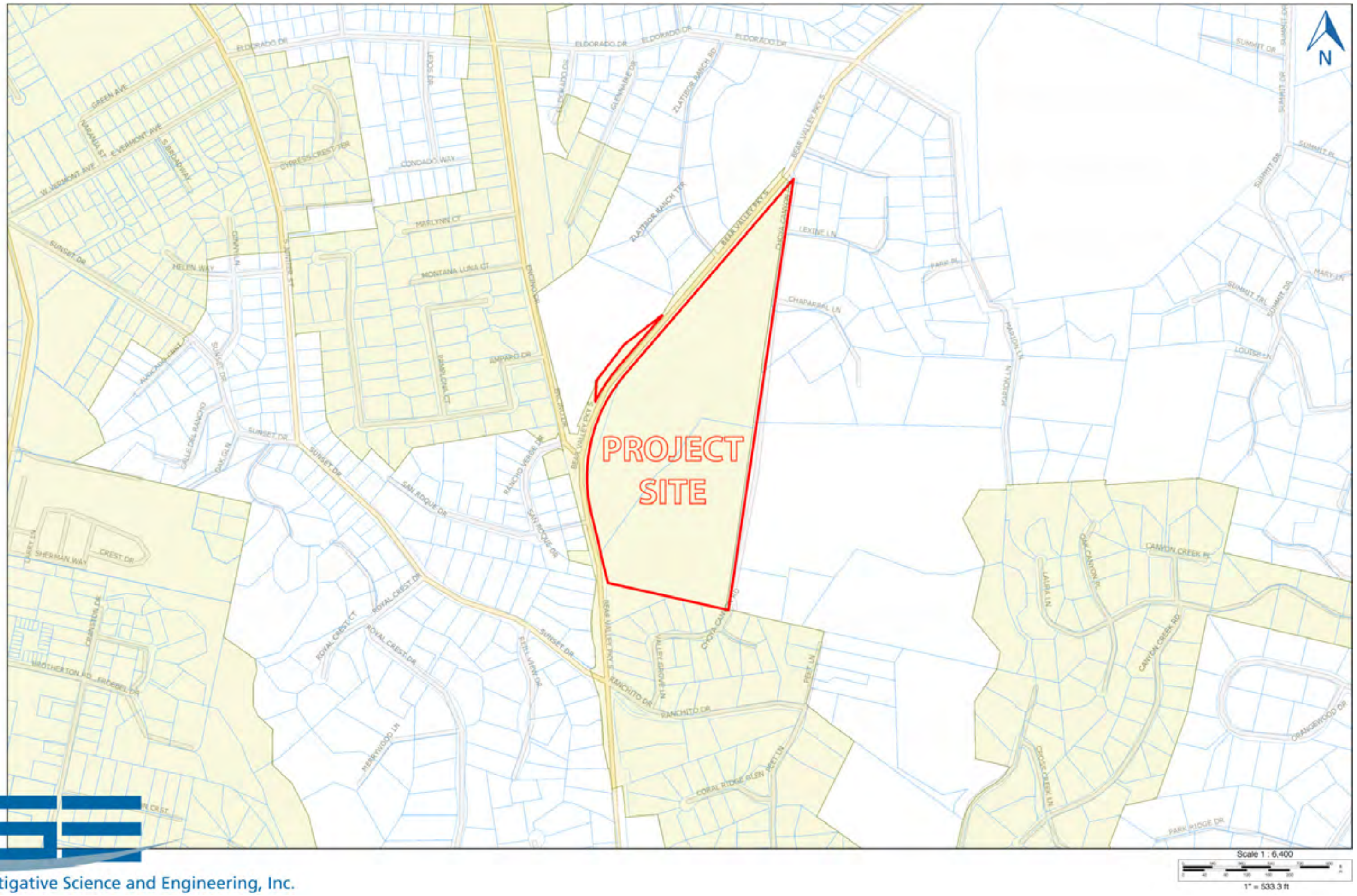

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FIGURE 2: Project Study Area Parcel Map (ISE 12/14)

FIGURE 3: Aerial Image Showing 661 Bear Valley Development and Surrounding Uses (ISE 12/14)

FIGURE 4: Proposed 661 Bear Valley Site Development Map (Hunsaker & Associates 12/14)

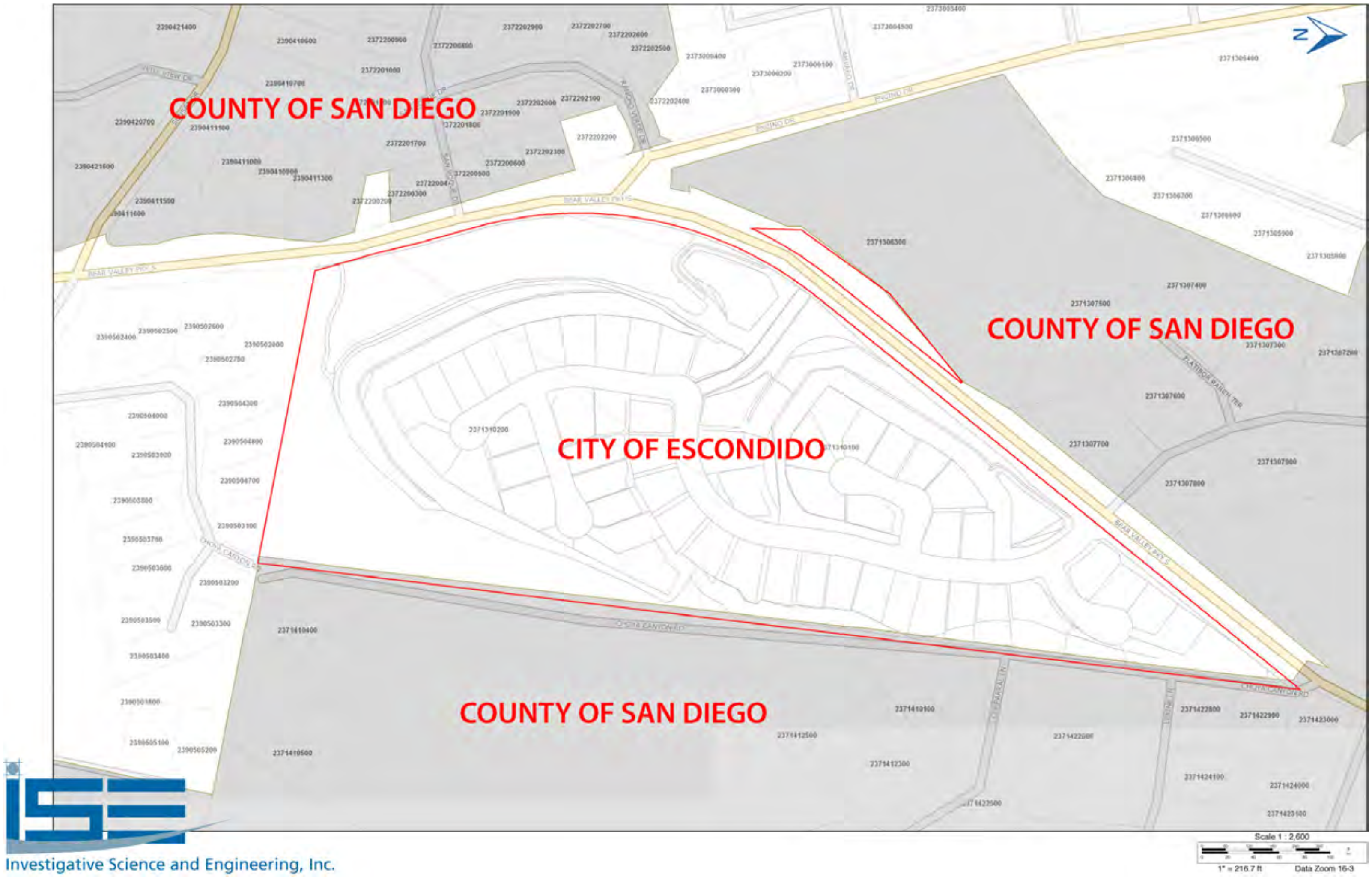


FIGURE 5: Development Site Relative to Surrounding Parcels (ISE 4/16)

As the frequency of the excitation approaches one of the object's natural frequencies, the magnitude of the object's vibratory response increases. When the two frequencies are exactly the same, a condition known as *resonance* arises. At resonance, the amplitude of the response approaches infinity. The only natural mechanism available to temper the catastrophic effects of resonance is a quantity known as 'damping'.[1]

In structures, or soils and rock, damping is generally present within the material itself and hence is called 'material damping'. The cause of this damping is due to the interactions between the molecular lattice structures comprising the material.

Vibration energy travels along the surface of a soil using a mechanism known as 'Rayleigh waves'. A Rayleigh wave is a seismic wave producing retrograde elliptical ground motion, and having no transverse, or perpendicular, components. This type of motion can seen visually in Figure 6 to the right. Rayleigh waves have the slowest decay rate of any seismic wave.

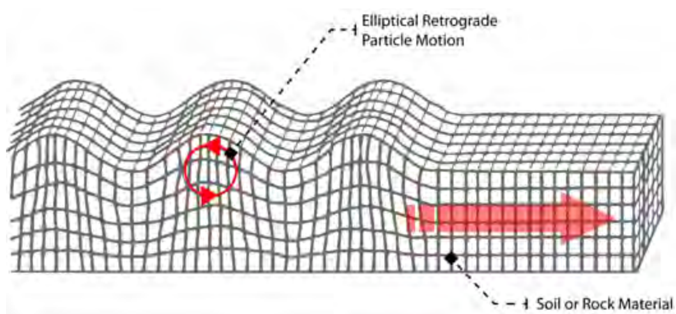


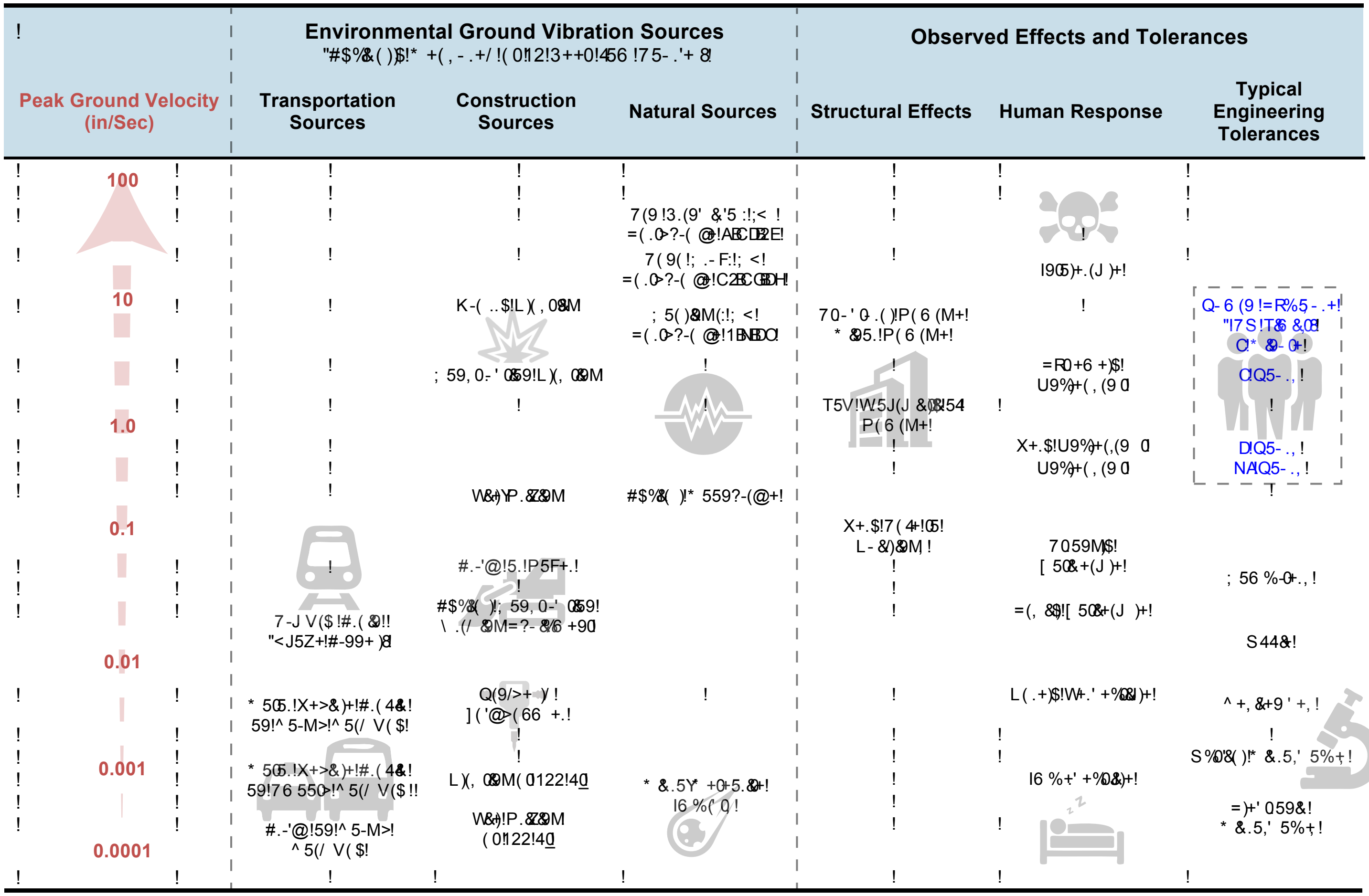
FIGURE 6: Typical Rayleigh Wave Propagation Profile (ISE 4/16)

Damping of surface waves in soils typically occurs as a combination of distance attenuation called 'radiation damping' and the aforementioned material damping. The latter is commonly approximated using a linear damping model that assumes the overall material damping increases as a function of distance between the source and receiver (i.e., the more soil between the source and receiver, the greater the mass, and the greater the material damping).

Table 1 on the following page provides a tabular representation of typical vibration sources and their effects on buildings, equipment, and humans. The peak ground velocity produced by various disturbances is given throughout a wide spectrum ranging from the infinitesimal to the severe. For most practical applications, induced vibration is a thing to be avoided, since the phenomenon is typically associated with physical discomfort, misalignment of equipment, loosening of mechanical fasteners, product defects, and skewed research results. In the case where the excitation frequency is close to resonance, or of sufficient magnitude (such as in an earthquake), severe structural damage can occur.

[1] Damping can be thought of as a type of 'drag force or resistance' that is always present to some degree in an object and serves to remove energy from the vibrating system as it moves. Artificial damping is used routinely in mechanical devices and takes the form of shock absorbers, viscous isolation materials, and simple friction.

TABLE 1: Typical Vibration Sources and Sensitivities



THRESHOLDS OF SIGNIFICANCE

Numerous ground vibration standards exist to provide a general indication as to the adverse effects of ground motion on structural systems and humans. All standards provide effectively the same threshold levels based on field investigations of displacement, fatigue, and damage in conventionally constructed structures (i.e., structures built within the past 100 years). The two most common standards will be used as a threshold indicator in this report.

U.S. Bureau of Mines RI 8507 / Swiss SN640 312 Vibration Criteria

The United States Bureau of Mines provides a well-defined impact guide to vibration on structures. This criteria, which was originally developed to catalog the observable effects of blasting on structures, has been accepted for all types of ground vibration excitation, since the fundamental parameter in all cases is the peak particle velocity of the receiving structure.[2]

A modern variant based on the Bureau of Mines research, was developed under Swiss Standard SN640 312, and is applied in Europe and the United States for the purpose of limiting vibration to sensitive resource areas. These threshold levels are shown in Table 2, and will be applied as the structural construction impact threshold for the 661 Bear Valley Tentative Subdivision as it constitutes the most conservative ground motion threshold for proposed construction activities.

TABLE 2: Construction Vibration Thresholds of Significance

Vibration Frequency (Hz.)	Maximum Peak Particle Velocity (in/sec)	Maximum Peak Particle Velocity (VdB re. 1.0 µin/sec)
< 30	0.12	101.6
30 to 60	0.15	103.5
> 60	0.24	107.6

Human Vibration Standards

The International Organization for Standardization (ISO) Standard 2631 Part 2 entitled "*Evaluation of human exposure to whole body vibration - Continuous and shock induced vibration in buildings*" contains guidelines pertaining to human exposure to vibration. The recommended continuous excitation levels are based upon various types of activities and building occupancy. The ISO human vibration standards are shown in the last column of Table 1. These standards are only applicable in cases where adverse impacts, or annoyance, to humans are suspected to be encountered.

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[2] The standards are based upon the Bureau of Mines report RI 8507 entitled "*Structure Response and Damage Produced by Ground Vibrations from Surface Blasting*". This criterion presented, which is similar to the earlier Bureau of Mines *Bulletin 656*, sets the maximum peak particle velocity as a function of frequency.

APPROACH AND METHODOLOGY

Dynamic soil testing at the 661 Bear Valley Tentative Subdivision was performed on 5/18/16 using two Kinemetrics *Ranger Model SS-1* moving-coil short period field seismometers as shown in Figure 7.[3] The seismometers were connected through shielded coaxial cable to a two-channel Larson Davis Model 2900 FFT spectrum analyzer for analysis and recording.[4]

For the testing in question, ISE instrumented an area adjacent to an existing onsite access road with the seismometers positioned exactly 50-feet apart in the vertical 'z-axis' response direction. The measurement spectrum examined, ranged between 0.8 Hz and 10 kHz, which is greater than the entire usable range of expected civil vibration problems. The cable length used was at least 100 feet to ensure adequate isolation of the experimenter and the monitoring location. The generator constants for the seismometers used was 8,457 mV/in/sec and 9,070 mV/in/sec with natural periods of one second each.

FIGURE 7: Typical Seismometer Configuration (ISE 5/16)

A series of hammer blows was applied to a four-inch-square cross-sectional wooden block using a rubber mallet. This impulse generated a uniform transverse (shear) stress wave in the soil in accordance with Saint-Venant's Principle. The resulting ground motion, as a function of frequency, was measured at the closest (source) seismometer, as well as at the 50-foot distant (receiver) seismometer. Subtracting the resulting waveforms, and correcting for geometric attenuation, provided an estimate of the material damping present in the soil as a function of frequency. The measured results were then frequency-truncated at a point where it was observed that no ground excitation due to the hammer blow was indicated. This was typically around 500 Hz.

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[3] These instruments, which are the terrestrial version of the lunar seismometer developed for NASA, are direct velocity-reading instrument capable of measuring inertial changes into the micro-inch-per-second range (the equivalent of footfalls one city block away).

[4] All testing and calibration is performed by ISE's Acoustics and Vibration Laboratory using a LORAN-C and Rubidium atomic frequency and time standard traceable to National Institute of Standards & Technology (NIST). The time and frequency calibration signal has a long-term stability of 10^{-10}. Specifications for traceability can be obtained at *www.nist.gov*.

FINDINGS AND RECOMMENDATIONS

Existing Soil Conditions

The area containing the 661 Bear Valley Tentative Subdivision is of a Cieneba Series Type and Chino Series type, as shown in Figure 8 on Page 12 of this report. Cieneba soils consist of very shallow to moderately shallow, somewhat excessively drained soils that form in weathered granitic rock, while Chino soils have a gray, calcareous, silty clay loam texture. Both types occur on hills and mountains that have slopes of between nine to 85 percent.[5,6]

Dynamic Soil Testing Findings

The results of the dynamic soil testing are shown in Figure 9 on Page 13 of this report. The testing indicated a high level of surface wave attenuation as a function of frequency.

Between 1.0 to 160 Hz. there is an increasing trend of greater soil damping reaching a peak level of 1.13 dB/ft signal loss in the 160 Hz band. Above 160 Hz. a drop in signal attenuation was noted with no attenuation being indicated above 1,250 Hz. No appreciable change in ground motion was observed above approximately 500 Hz, so a frequency cut-off of 500 Hz. was applied to the data. Throughout the entire frequency range of interest (1.0 to 500 Hz.), the RMS soil attenuation level was found to be 0.56 dB/ft.

Required Construction Setback Distances

Solving the general equation for radiation damping due to a Rayleigh wave under an assumed linear soil damping model, one can numerically back-calculate the required separation distance from a known ground excitation event to achieve compliance with the SN640 312 standard shown previously shown in Table 2.

Construction methods for the 661 Bear Valley Tentative Subdivision project could produce worst-case impulsive ground excitation of no more than 1.0 in/sec peak particle velocity PPV (120.0 VdB PPV). This maximum level was utilized for the purposes of calculation of a recommended setback distance from any sensitive area within the project site. The results are shown in Table 3 on Page 14 of this report.

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[5] Source: United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Series Database, 5/16.

[6] These soil types are located within the following taxonomic classes: Cieneba = CIENEBA LOAMY, MIXED, SUPERACTIVE, NONACID, THERMIC, SHALLOW TYPIC XERORTHENTS; CHINO = FINE-LOAMY, MIXED, SUPERACTIVE, THERMIC AQUIC HAPLOXEROLLS.

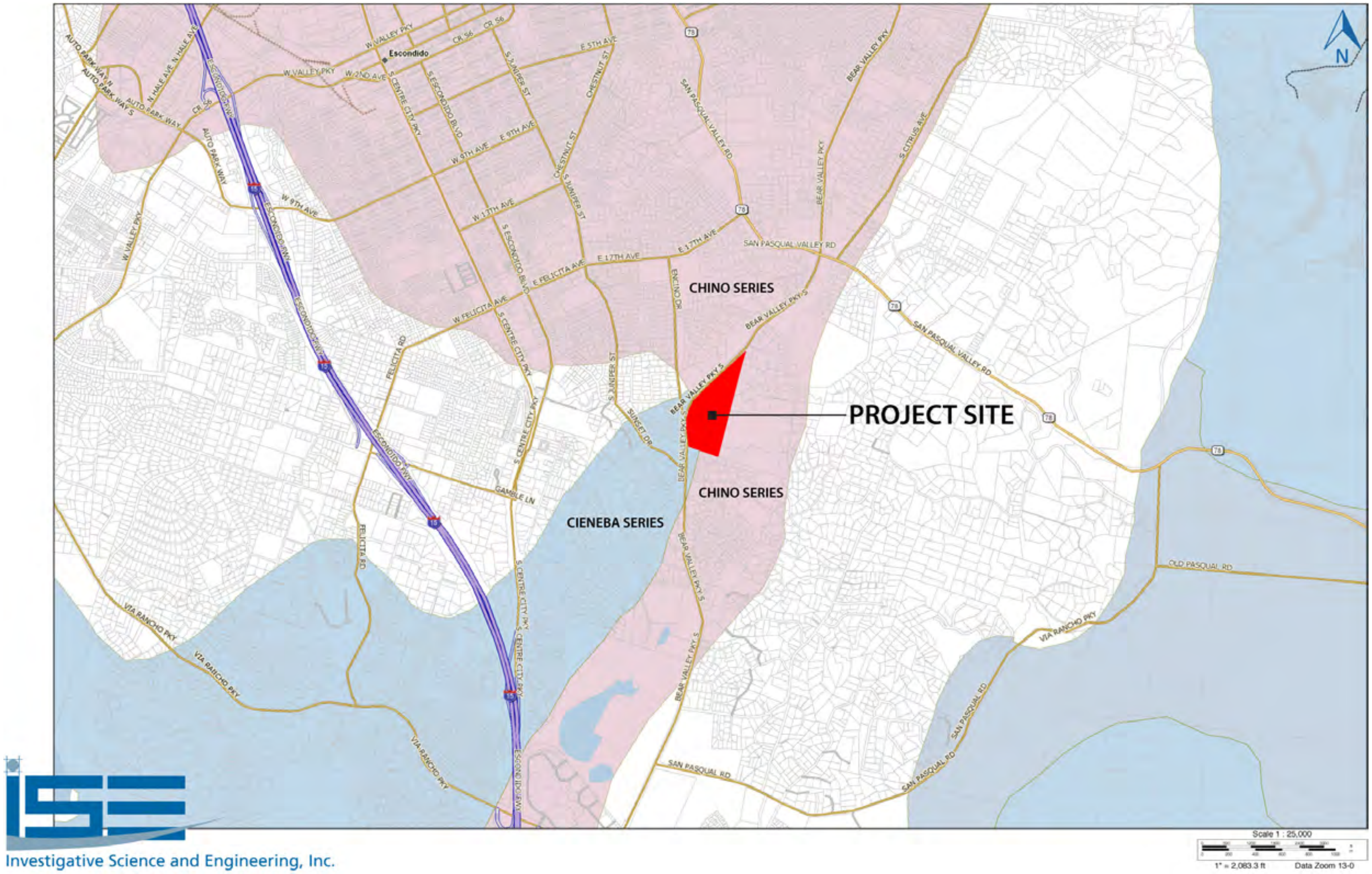

FIGURE 8: Soil Conditions Surrounding Project Site (ISE 5/16)

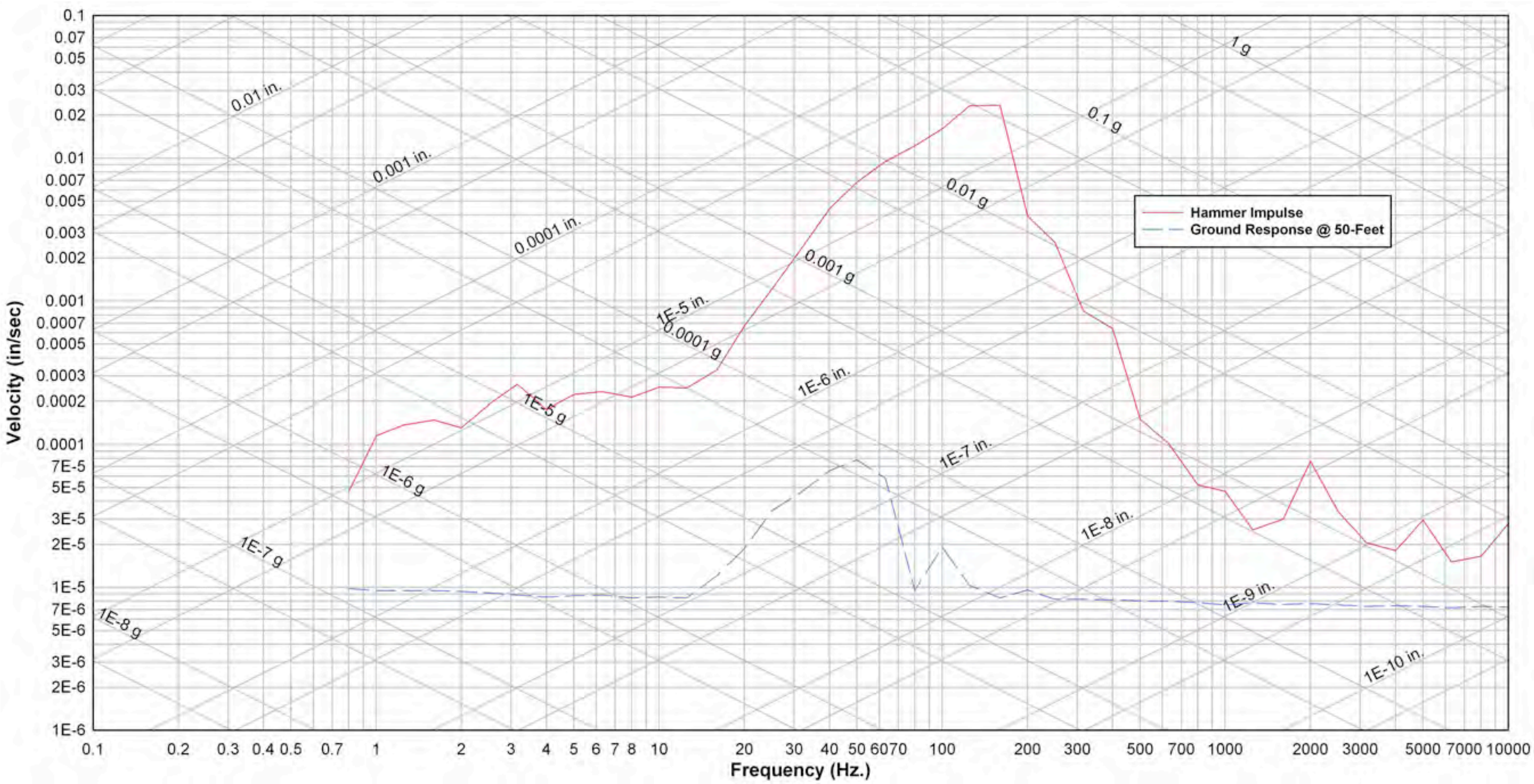

FIGURE 9: Measured Dynamic Soil Response at 661 Bear Valley Tentative Subdivision Site (ISE 5/16)

TABLE 3: Recommended Construction Setback Distances

One-Third Octave Band Vibration Frequency Component (Hz.)	Maximum Allowable Peak Particle Velocity (VdB re. 1.0 μin/sec)	Minimum Recommended Setback Distances in Feet for 1.0 in/sec Ground Excitation
1	101.6	73
1.25	101.6	65
1.6	101.6	62
2	101.6	66
2.5	101.6	54
3.15	101.6	46
4	101.6	54
5	101.6	49
6.3	101.6	48
8	101.6	49
10	101.6	46
12.5	101.6	46
16	101.6	47
20	101.6	43
25	101.6	43
31.5	103.5	35
40	103.5	32
50	103.5	30
63	103.5	26
80	107.6	15
100	107.6	16
125	107.6	14
160	107.6	13
200	107.6	17
250	107.6	18
315	107.6	23
400	107.6	24
500	107.6	39

Thus, for anticipated ground excitation not exceeding 1.0 in/sec PPV, the separation distances shown in Table 3 were found to be adequate to preclude the presence of an impact to either structures or humans. No additional measures would be necessary.

CERTIFICATION OF ACCURACY AND QUALIFICATIONS

This report was prepared by Investigative Science and Engineering, Inc. (ISE). The members of its professional staff contributing to the report are listed below:

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ISE affirms to the best of its knowledge and belief that the statements and information contained herein are in all respects true and correct as of the date of this report. Content and information contained within this report is intended only for the subject project and is protected under 17 U.S.C. §§ 101 through 810.

Should the reader have any questions regarding the findings and conclusions presented in this report, please do not hesitate to contact ISE at (760) 787-0016.

Approved as to Form and Content:

Rick Tavares

Rick Tavares, Ph.D.

Project Principal
Investigative Science and Engineering, Inc. (ISE)

INDEX OF IMPORTANT TERMS