Sacramento Intermodal Transportation Facility

Noise Study Report

Sacramento, California

HPL – 5002(090)

EA 03-0L0364L

February 2009

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California Department of Transportation

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District/Region ______________________

Summary

The City of Sacramento (City) proposes to construct modifications to the Southern Pacific Depot (Depot) in downtown Sacramento. This report evaluates noise and vibration impacts associated with the proposed project.

The initial phases (Phase 1 and Phase 2) would be funded primarily with local and state funding, as well as possibly Federal Railroad Administration (FRA) funding, in addition to Federal Highway Administration (FHWA) funding. Implementation of future Phase 3 depends on future service expansion and passenger growth, and approval of future federal funding allocations. FHWA is the federal lead agency under the National Environmental Policy Act (NEPA), with the California Department of Transportation (Caltrans) serving as its representative. FRA and Federal Transit Administration (FTA) are cooperating agencies.

Because FHWA is the NEPA lead agency with Caltrans as its representative, this report has been prepared in accordance with FHWA/Caltrans guidance for noise study reports (NSRs). In addition to addressing the requirements of FHWA, this report addresses FTA and FRA requirements.

The City proposes to expand the existing Sacramento Valley Station (Station) to meet current needs and to establish a state-of-the-art regional transportation center to meet future needs of rail and bus transit passengers and service operators in the Sacramento region through 2025 and beyond. The Sacramento Intermodal Transportation Facility (SITF) (proposed project) would be developed in the following three phases:

- **Phase 1—**a realignment of existing mainline rail tracks
- **Phase 2—**improvements to the existing Station
- **Phase 3—**eventual transformation of the Station into a multimodal transportation center

Two build alternatives, in addition to the No-Build Alternative, are evaluated: Alternative 1, “Don’t Move the Depot” and Alternative 2, “Move the Depot”.

Because there are no off-site roadway improvements included in the proposed project, the proposed project is not a Type I project as defined in FHWA regulations (23 Code of Federal Regulations [CFR] 772). Accordingly, no evaluation of operational traffic noise

is required under 23 CFR 772, and this analysis focuses on noise and vibration criteria specified by FTA.

Implementation of the proposed project is not predicted to result in any adverse traffic noise impacts. Realignment of the track will allow trains to travel faster through the area. This is predicted to result Severe Impacts, as defined by FTA, at residential uses located east of the project site. Potential mitigation includes limiting train speeds in the area or constructing a noise barrier.

Realignment of the track is predicted to result in groundborne vibration at historic buildings on the project site that exceeds FTA damage criteria for fragile buildings. Realignment of the track is also predicted to exceed FTA groundborne vibration and noise criteria for occupied buildings that will be constructed in the future. Mitigation measures that include increasing the distance to buildings, soil densification, construction of trenches, use of piles under the track bed, use of tired-derived aggregate, and use of floating slab for track support are discussed.

Construction of the proposed project is predicted to result in construction noise that exceeds FTA guidance for noise and vibration. Measures to limit construction and vibration are discussed.

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List of Abbreviated Terms

BART	San Francisco Bay Area Rapid Transit District
Caltrans	California Department of Transportation
CFR	Code of Federal Regulations
City	City of Sacramento
CNEL	Community noise equivalent level
dB	Decibels
dBA	A-weighted decibels
Depot	Southern Pacific Depot
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
Hz	Hertz
I-5	Interstate 5
in/sec	Inches/second
kHz	Kilohertz
L_{dn}	Day-night level
L_{eq}	Equivalent sound level
L_{eq}(h)	1-hour A-weighted equivalent sound level
L_{max}	Maximum sound level
LRT	light rail transit
L_{xx}	Percentile-exceeded sound level
mPa	Micro-Pascals
mph	Miles per hour
NAC	Noise abatement criteria
NEPA	National Environmental Policy Act
NSR	Noise study report
Protocol	*Traffic Noise Analysis Protocol for New Highway Construction, Reconstruction, and Retrofit Barrier Projects*
r.m.s.	Root mean square
RT	Sacramento Regional Transit District
SITF	Sacramento Intermodal Transportation Facility
SPL	Sound pressure level
Station	Sacramento Valley Station
TDA	Tire-derived aggregate
TeNS	*Technical Noise Supplement*

TNM 2.5	Traffic Noise Model Version 2.5
UPRR	Union Pacific Railroad
VdB	vibration decibels

Chapter 1. Introduction

The City of Sacramento (City) proposes to construct modifications to the Southern Pacific Depot (Depot) in downtown Sacramento. Figure 1-1 shows the project vicinity, and Figure 1-2 shows the project location.

Modifications to the facility, which will ultimately be called the Sacramento Valley Station (Station), will be conducted in multiple phases. The initial phases (Phase 1 and Phase 2) would be funded primarily with local and state funding, as well as possibly Federal Railroad Administration (FRA) funding, in addition to Federal Highway Administration (FHWA) funding. Future phases depend on FHWA and Federal Transit Administration (FTA), with local and state funding used as matching funds. Both FHWA and FTA have provided funding for planning and technical studies, as well as ongoing repairs and minor improvements to the existing Depot. Future FHWA and FTA funding, which has already been appropriated, would be used to fund improvements to the Station as described herein.

The FHWA is the federal lead agency under the National Environmental Policy Act (NEPA) with the California Department of Transportation (Caltrans) serving as its representative. FRA and FTA are cooperating agencies.

Because FHWA is the NEPA lead agency with Caltrans as its representative, this report has been prepared in accordance with FHWA/Caltrans guidance for noise study reports (NSRs). In addition to addressing the requirements of FHWA, this report addresses FTA and FRA requirements.

1.1. Purpose of the Noise Study Report

The purpose of this NSR is to evaluate noise impacts and abatement under the requirements of Title 23, Part 772 of the Code of Federal Regulations (23 CFR 772) “Procedures for Abatement of Highway Traffic Noise,” which provides procedures for preparing operational and construction noise studies and evaluating noise abatement considered for federal and federal-aid highway projects. This report also evaluates noise and vibration impacts in accordance with FTA guidance presented in the document entitled *Transit Noise and Vibration Impact Assessment* (FTA 2006). FRA criteria and methodology for noise and vibration are similar to the FTA criteria and methodology for noise and vibration.

Caltrans' *Traffic Noise Analysis Protocol for New Highway Construction, Reconstruction, and Retrofit Barrier Projects* (Protocol) (Caltrans 2006) provides Caltrans policy for implementing 23 CFR 772 in California. The Protocol outlines the requirements for preparing NSRs.

1.2. Project Purpose and Need

1.2.1. Purpose

The proposed project is a mass transportation project and is intended to enhance and upgrade existing mass transit facilities as well as provide new transit facilities, thereby meeting existing and projected future user and provider needs and facilitating multiple forms of transportation modes, including rail, transit, pedestrian, and bicycle. The project would also help to decrease the Sacramento region's reliance on automobiles and remove traffic from the interstate and highway system, as well as accommodate a future high-speed-rail project, which may be developed by the state.

Specifically, the City intends to accomplish the following improvements.

1.2.1.1. Rail and Transit Service

- Improve capacity and reliability for freight and passenger rail service.
- Reduce rail and passenger conflicts and improve safety.
- Provide improved connectivity and ease of use for transit and rail users and providers.
- Accommodate future expansion of rail and bus services by providers that currently operate at the existing Depot and potential new users and providers.
- Increase local and regional transit use by bringing together disconnected elements of the transit network into a single regional hub.
- Meet projected service levels and passenger growth.

1.2.1.2. Road and Highway System

- Help to decrease the Sacramento region's reliance on automobiles and remove traffic from the interstate and highway system. Although the City does not propose physical improvements to the state highway system or the local roads as part of the proposed project, improving rail and transit service would provide alternative modes of transportation to the Sacramento region.

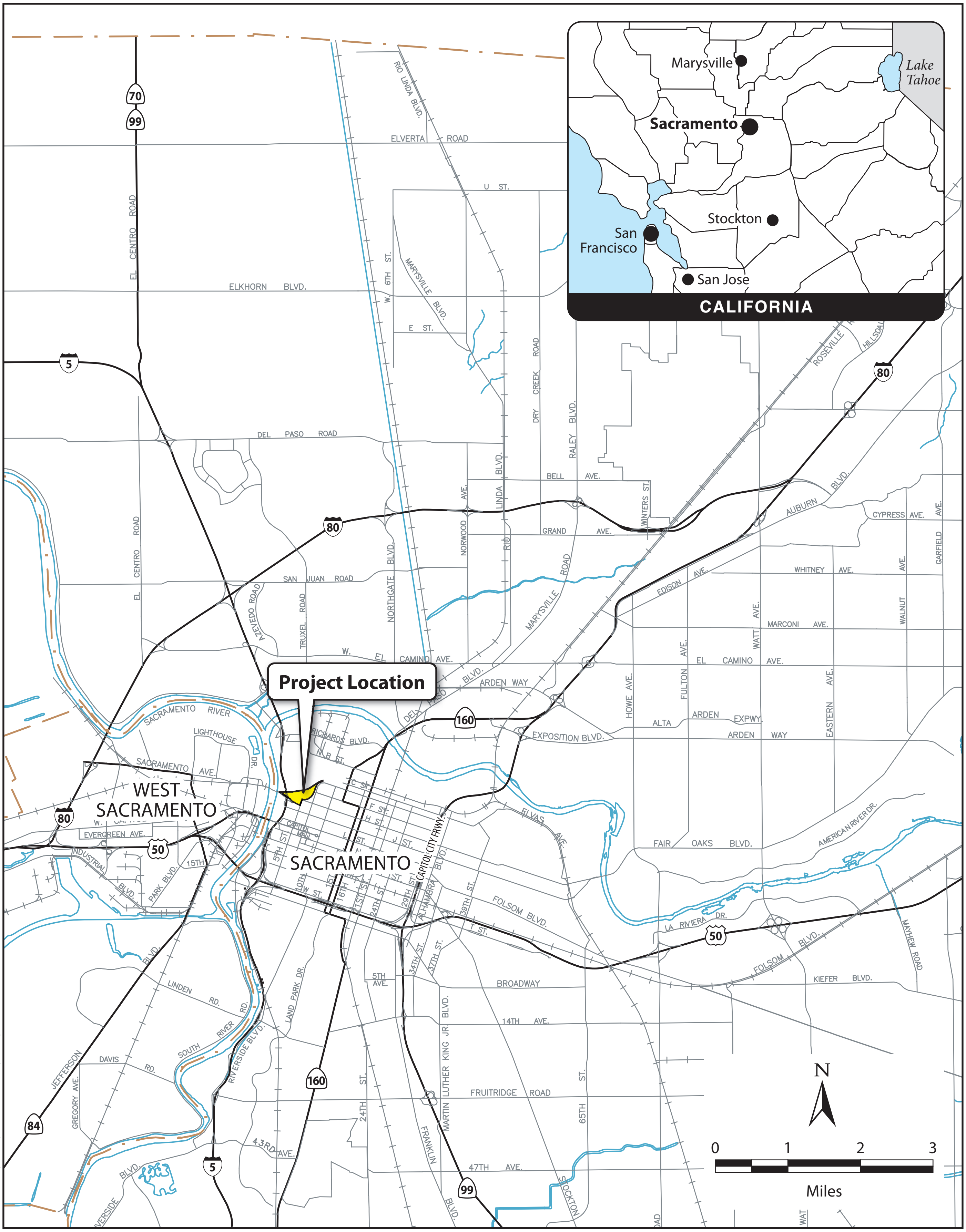

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Figure 1-1
Project Vicinity

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Figure 1-2
Project Location

1.2.2. Need

There have been five train terminals at various locations in downtown Sacramento, beginning with the first Central Pacific Terminal built in 1879 and culminating with the current Depot built in 1925, which is the only facility in Sacramento remaining in regular passenger service. As originally built, the Depot had a direct relationship to the main civic corridor of I Street, connecting arriving and departing passengers directly to the downtown core via 4th and I Streets. This connection has been compromised in a number of ways, including by construction of the Interstate 5 (I-5) on-ramp and the installation of heavy landscaping. Pedestrians wishing to access the Depot must navigate a heavily trafficked intersection and walk through several parking lots to reach the Depot main entrance.

Currently, the Depot houses the Sacramento Amtrak station; operations for interstate passenger rail service and the Capitol Corridor and San Joaquin Corridor intercity services; the existing Union Pacific Railroad (UPRR) freight rail lines, passenger platforms, and tunnel; Sacramento Regional Transit District's (RT's) light rail transit (LRT) line and station; bus loading areas for multiple service providers; and passenger parking. The Depot and all of its associated facilities are known as the Sacramento Valley Station (Station). The use of the Depot has increased substantially over the past several years with the addition of Capitol Corridor trains to meet the increasing commuter demand between the San Francisco Bay Area (Bay Area) and Sacramento and the addition of the LRT. The existing Depot facilities are undersized and deficient in ticketing, baggage handling, administrative areas, the number of berths for buses, and passenger amenities (such as food and services purveyors).

The UPRR mainline tracks located directly north of the Depot are shared by the Capitol Corridor intercity rail service, which operates passenger service between the Bay Area and Auburn; the Amtrak transcontinental passenger service; and the San Joaquin Corridor rail service, which operates between Sacramento and Bakersfield. The existing track configuration substantially reduces the velocity at which freight trains can pass through the area. Freight trains are also delayed ("held out") to wait for passenger trains at the Station to load and unload passengers.

The proposed project is needed for the following reasons.

1.2.2.1. RAIL AND TRANSIT SERVICE

- The current alignment of the UPRR track between 2nd Street and 7th Street does not meet the operational capacity requirements of the freight and passenger operators. As noted above, the UPRR mainline tracks are shared by the Capitol Corridor intercity rail service, which operates passenger service between the Bay Area and Auburn; the Amtrak transcontinental passenger service; and the San Joaquin Corridor rail service, which operates between Sacramento and Bakersfield. The existing track configuration substantially reduces the velocity at which freight trains can pass through the area and limits the maximum length of the trains, thereby reducing capacity. Freight trains are also delayed ("held out") to wait for passenger trains at the station to load and unload passengers.

- The configuration of the LRT tracks immediately behind the Depot is not optimal for bus, vehicle and pedestrian access and safety.

- The current configuration of the LRT station and bus areas limits the ability of the site to accommodate additional transit providers.

- The existing Depot facilities are undersized and deficient in ticketing, baggage handling, administrative areas, the number of berths for buses, and passenger amenities (such as food and services purveyors).

- The existing demand for parking at the Depot exceeds the available supply.

- The existing baggage tunnel that extends from the north side of the Depot to the existing tracks is not compliant with the Americans with Disabilities Act (ADA). It cannot accommodate baggage carts with more than two trailers because of the 90-degree turns required to move between the tunnel and the ramps to the platforms. This requires multiple runs of cars for many Amtrak trains in the short time they stop at the Station.

- An all-weather and well-lighted pathway, including for the use of passenger carts and Red-Cap Service for mobility-impaired passengers, is needed to provide for passenger safety and convenience.

1.2.2.2. ROAD AND HIGHWAY SYSTEM

- Many of the Sacramento area freeway mainline study segments operate at unacceptable levels of service during peak periods, and many segments are near capacity. During congested conditions, drivers must divert to other routes, and fewer vehicles are able to get through than the actual demand would otherwise indicate, resulting in lower traffic counts and higher levels of service than are typically observed. (PBS&J/EIP 2007)

Chapter 2. Project Description

The City proposes to expand the existing Station to meet current needs and to establish a state-of-the-art regional transportation center to meet future needs of rail and bus transit passengers and service operators in the Sacramento region through 2025 and beyond. The Sacramento Intermodal Transportation Facility (SITF) (proposed project) would be developed in the following three phases:

- **Phase 1**—a realignment of existing mainline rail tracks
- **Phase 2**—improvements to the existing Station
- **Phase 3**—eventual transformation of the Station into a multimodal transportation center

Two build alternatives, in addition to the No-Build Alternative, are evaluated: Alternative 1, “Don’t Move the Depot” Alternative 2, “Move the Depot”.

The build alternatives are identical in design for Phases 1 and 2 and differ only in the design of the ultimate intermodal facility in Phase 3. The improvements proposed in Phases 1 and 2 are independent of the future decision of whether to move the Depot. The Phase 1 track relocation activities do not depend on implementation of Phase 2, nor do the Phase 1 improvements foreclose alternatives (location and size) of the Phase 2 improvements. Similarly, the Phase 1 nor Phase 2 improvements do not depend on or foreclose the alternatives for the future implementation of Phase 3, irrespective of the future decision to relocate the Depot.

For all project phases, construction staging, equipment lay down, and access and material storage for all work would occur within the “footprint” of the project site (the area of ground disturbance) or on existing access roads. Track installation materials would be brought in by rail. Traffic control plans specifying signage, detours, flagmen, and other traffic control measures will be implemented to the satisfaction of the City Development Engineering Division to maintain access and safety for all modes of travel during construction of all phases.

Phase 1 would be constructed and fully operational in 2010. Phase 2 would start construction in the first quarter of 2011, after the completion of Phase 1, and would be completed in approximately 3 years. The timing of future Phase 3 is uncertain and depends on the build alternative selected and the availability of funding. FHWA will not authorize construction, at the conclusion of this environmental process, the final design or Federal funding for any right-of-way acquisition for future Phase 3.

There are no off-site roadway improvements proposed as part of the proposed project.

2.1. No-Build Alternative

Under the no-build alternative, no phases of the project would be constructed. The existing Depot would remain under its existing uses, would not be restored, and would remain difficult to access by the general public. The tracks would remain in their current configuration, and the platforms could not be expanded, resulting in deteriorating levels of service to passengers and providers. No upgraded Station facilities would be constructed, and consequently ongoing maintenance costs of the unimproved facilities would be likely to increase. Because of the track configuration, UPRR trains would continue to operate at lower-than-optimum speeds and at shorter overall length, under-using their potential freight movement capacity. Conflicts between passenger and freight trains would continue to occur, or increase, resulting in continued delay of freight trains. Freight trains forced to stop and wait as a result of passenger conflicts would further impede goods movement, and the idling locomotives would create localized and regional air quality impacts. The existing Depot facilities and platforms would not be able to accommodate projected increases in passengers, and use could decline or grow at a slower rate than anticipated, resulting in a corresponding higher use of the vehicles and highway system.

2.2. Build Alternative—Phase 1

Phase 1 consists of the following components, which are identical for both build alternatives (Figure 2-1a – 2-1e):

- Preparing the new alignment for relocation of the existing mainline freight and passenger tracks.
- Installing new freight tracks, new passenger tracks, and associated equipment within the platform area.
- Constructing new double-sided passenger platforms.
- Constructing a new passenger platform tunnel (the Central Tunnel), service tunnel (West Service Tunnel), and pedestrian/bicycle tunnel (West Pedestrian/Bicycle Tunnel) under the relocated tracks.

- Constructing a pedestrian walkway from the passenger platform tunnel (Central Tunnel) to the Depot building on the south side of the rail corridor.

- Constructing a pedestrian connection from the passenger platform tunnel (Central Tunnel) to the north side of the rail corridor.

- Constructing a service access pathway from the Depot to the proposed new passenger tracks, consisting of a crossing of the tracks on the west side of the platforms (West Service Tunnel), the service roadway between the platforms, and the paved drive between the Depot and the crossing.

- Removing the existing mainline tracks and passenger platforms behind the Depot once the new track alignment was operational. The ramps to the platform that are part of the existing pedestrian tunnel at the Depot would be subsequently connected to the new walkway.

2.3. Build Alternative—Phase 2

Phase 2 would consist of improvements to the existing Station that would upgrade its facilities and relocate transportation uses for more efficient operations, including improvements to the existing Depot. Phase 2 consists of the following components, which are identical in both build alternatives (Figure 2-2a – 2-2b):

- Relocating, reconfiguring, and repaving/restriping the existing RT and Amtrak bus berths.

- Relocating the existing LRT station to a north-south alignment on the eastern edge of the site as planned by RT, which would create better internal site circulation and proximity to the bus berths and to the long-distance passenger rail service from LRT trains.

- Providing enhanced passenger connections, including walkway upgrades (e.g., street furniture, a shade/weather covering, and landscaping/lighting) from the new passenger platforms to the Depot and a tunnel extension that connects the existing Depot tunnel and the Central Tunnel constructed in Phase 1.

- Relocating and reconfiguring passenger vehicle and bicycle parking to accommodate existing parking demand and improve the drop-off area in front of the Depot.

- Upgrading the electrical system at the station and within the Depot to meet functional needs and requirements.

- Providing a transit way along the north side of the site connecting the west side of the facility to the extension of F Street to facilitate bus circulation on site and provide shortcuts separate from congested city streets.

The Phase 2 improvements would be constructed after the tracks have been relocated.

2.4. Build Alternative—Phase 3

Phase 3 consists of the following components, which differ between the build alternatives. Implementation of Phase 3 would be dependent on the availability of funding allocations.

- Converting the existing Station into a large, multimodal regional transportation facility designed to integrate a classic transportation building and the historic Sacramento setting with modern, “green” design that complies with the principles of social and ecological sustainability.

- Expanding bus bays.

- Expanding baggage facilities.

- Constructing multiple waiting areas.

- Expanding site features that serve passengers and providers.

- Meeting sustainable design objectives.

The ultimate intermodal facility in Phase 3 would include a new terminal building to accommodate projected service providers and passengers.

2.4.1. Components Specific to Alternative 1, “Don’t Move the Depot”

Under Alternative 1, “Don’t Move the Depot” (Figure 2-3), the following additional major features would be constructed in future Phase 3:

- Expanded regional bus (Greyhound) and Amtrak bus facilities in a multilevel concourse north of the existing Depot that would contain ticketing, administrative and waiting areas, leased support areas, and direct vertical connections to the bus boarding. In future Phase 3 under Alternative 1, the walking distances between the

Depot and the bus/LRT area would be approximately 655 feet and the distance from the Depot to the passenger rail platforms would be 765 and 835 feet, respectively.

- A concourse with skywalk (upper level) connections to the second floor of the existing Depot, to commercial development to the east, and to future joint development and parking structures to the west.
- A bridge overcrossing extending from the concourse level across the rail corridor to the passenger platforms and to the Central Shops.
- Multilevel terminal areas with overlooks, open and enclosed roof areas, landscape planters extending through levels, passenger walkways, way-finding measures, and user-friendly features. Connections between levels would be by means of stairs, elevators, and escalators.
- Modifications to the local bus area developed in Phase 2 to accommodate increased berths.
- Upgrades and adjustments to the location of the passenger walkway between the Depot and the passenger rail platforms immediately to the west of its existing location, including improved cover, landscaping, and urban design features.
- On-site building pads for a parking structure used for transit passenger parking.

2.4.2. Components Specific to Alternative 2, "Move the Depot"

Under Alternative 2, "Move the Depot" (Figure 2-4), additional major features constructed in Future Phase 3 would consist of the following:

- Construction of a new terminal building for Amtrak and Greyhound buses, baggage, and administrative and leased support areas situated across a plaza from the newly relocated historic Depot.
- Relocation of the existing Depot building approximately 300 feet to the north; the building would be jacked and rolled onto a new foundation (SMWM/Arup and Associated Consultants 2008a).
- Modified passenger/baggage tunnel between the terminal/Depot and the passenger platform tunnel.
- Joint development and public open space on the former Depot site.

- Modification of certain Phase 2 improvements, such as in the parking on the site and areas south of the original station location and between the old and new station sites, as required.

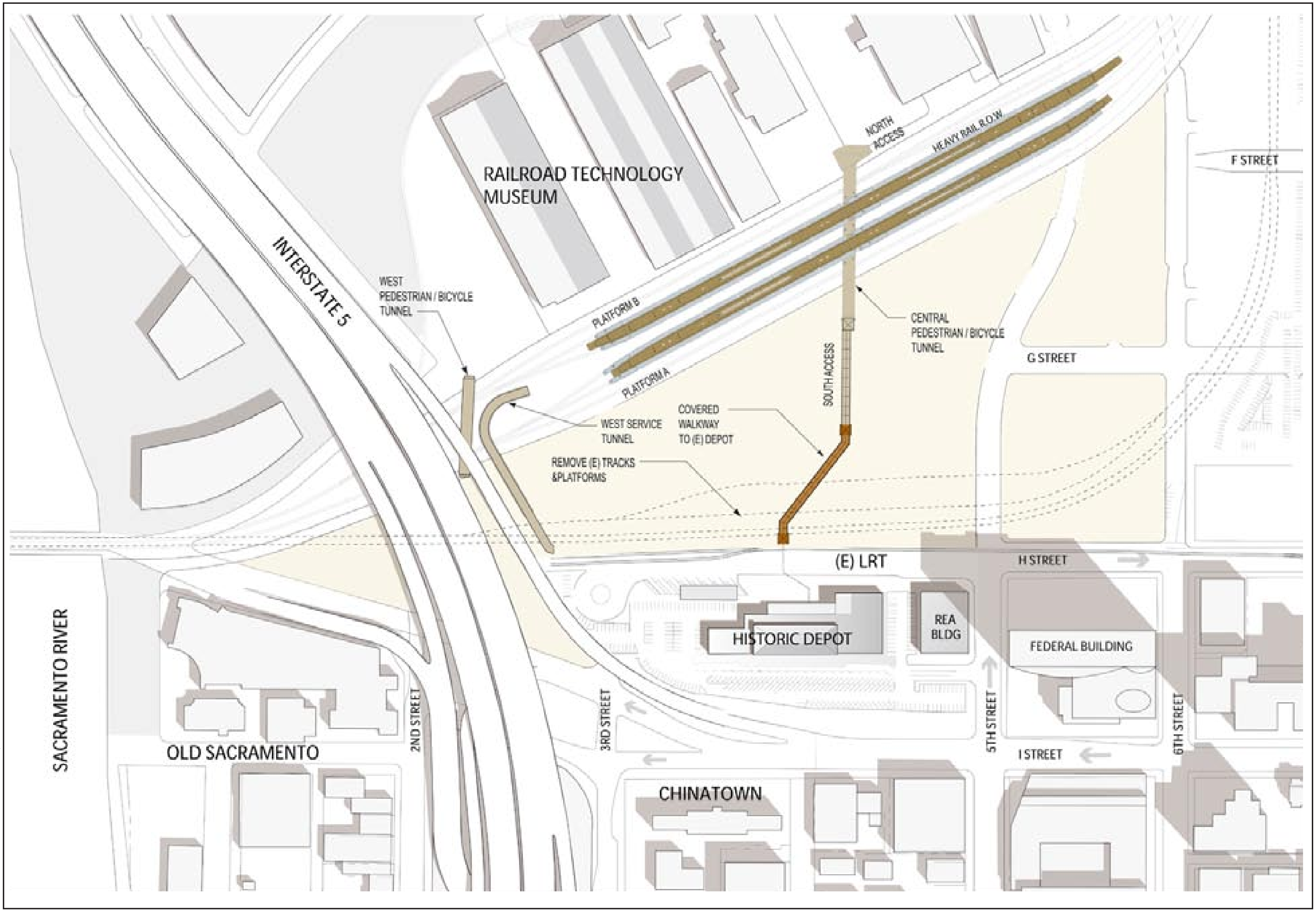

Figure 2-1a
Phase 1 Track Relocatiion

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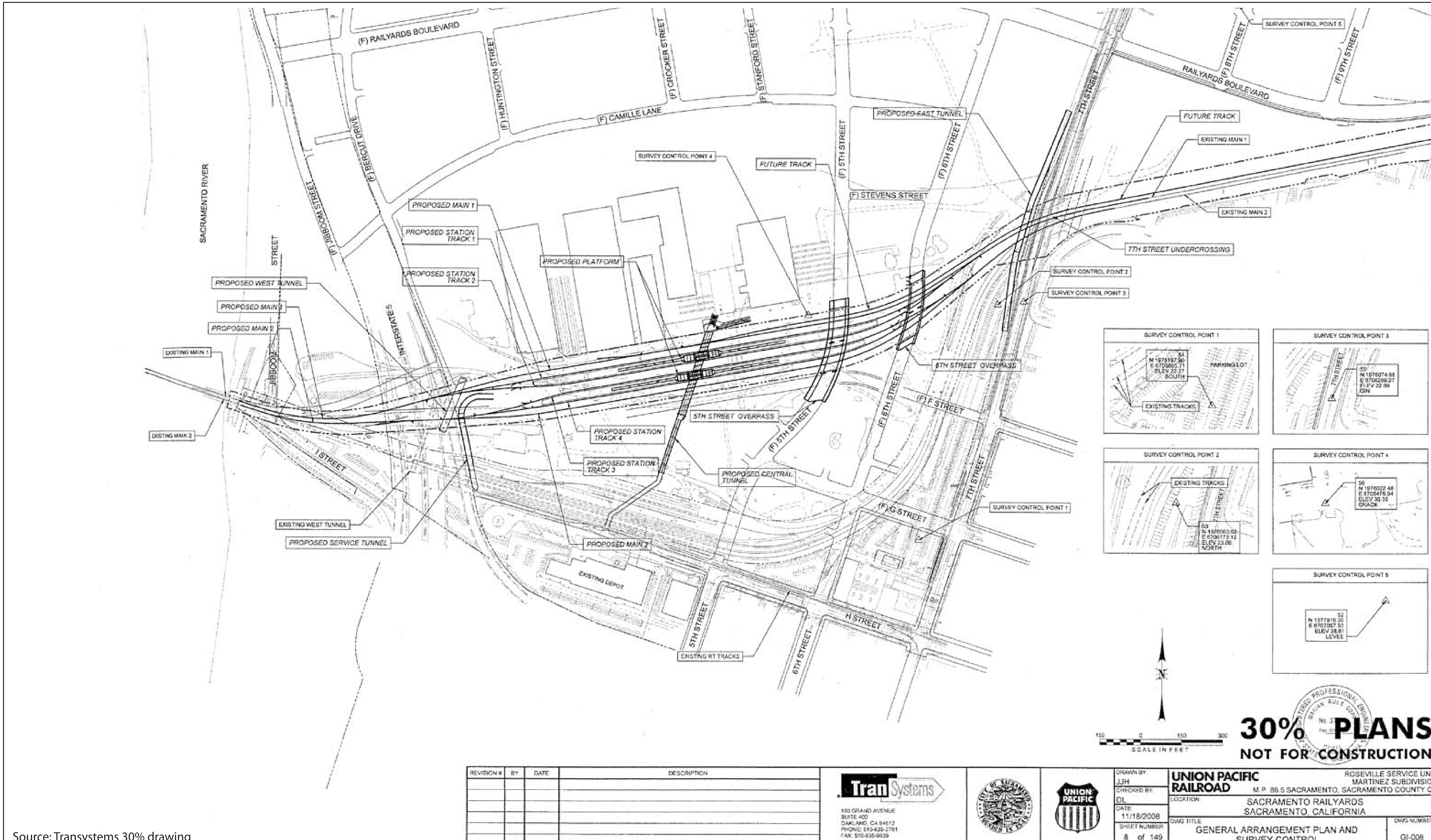

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Figure 2-1b
Phase 1: General Arrangement Plan

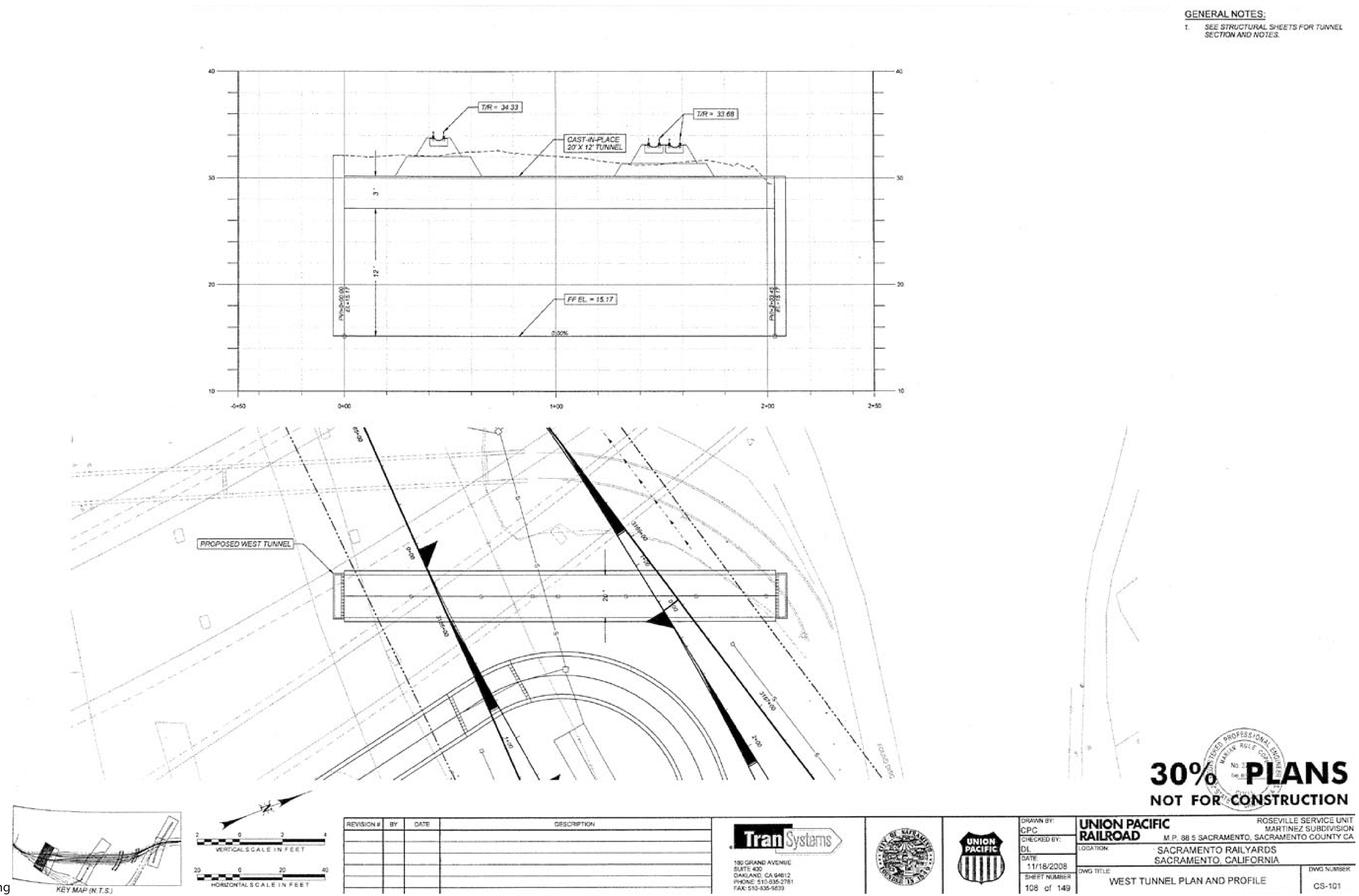

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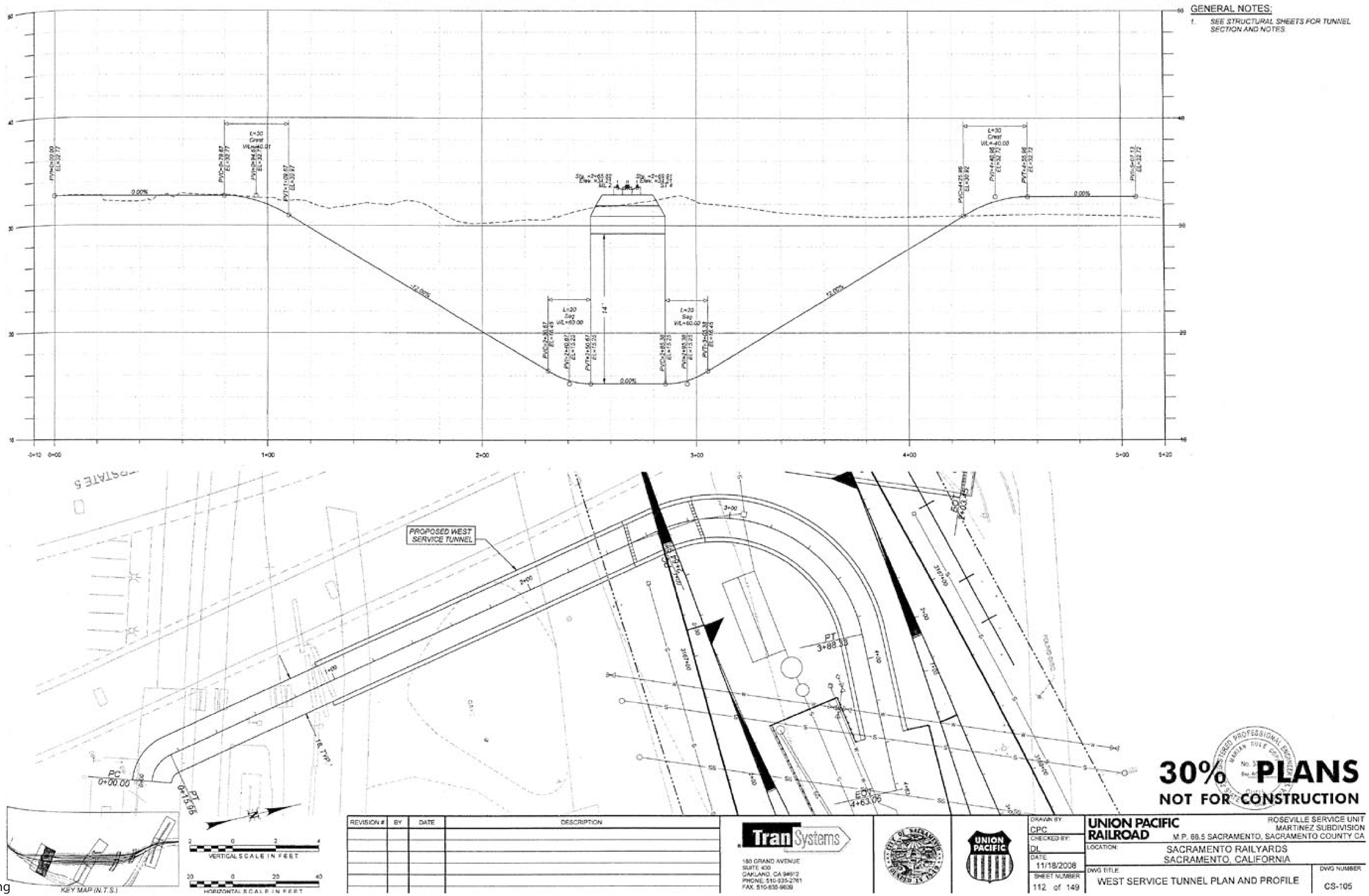
Figure 2-1c
Phase 1: West Pedestrian Tunnel Plan and Profile



Source: Transystems 30% drawing

Figure 2-1d
Phase 1: West Service Tunnel Plan and Profile

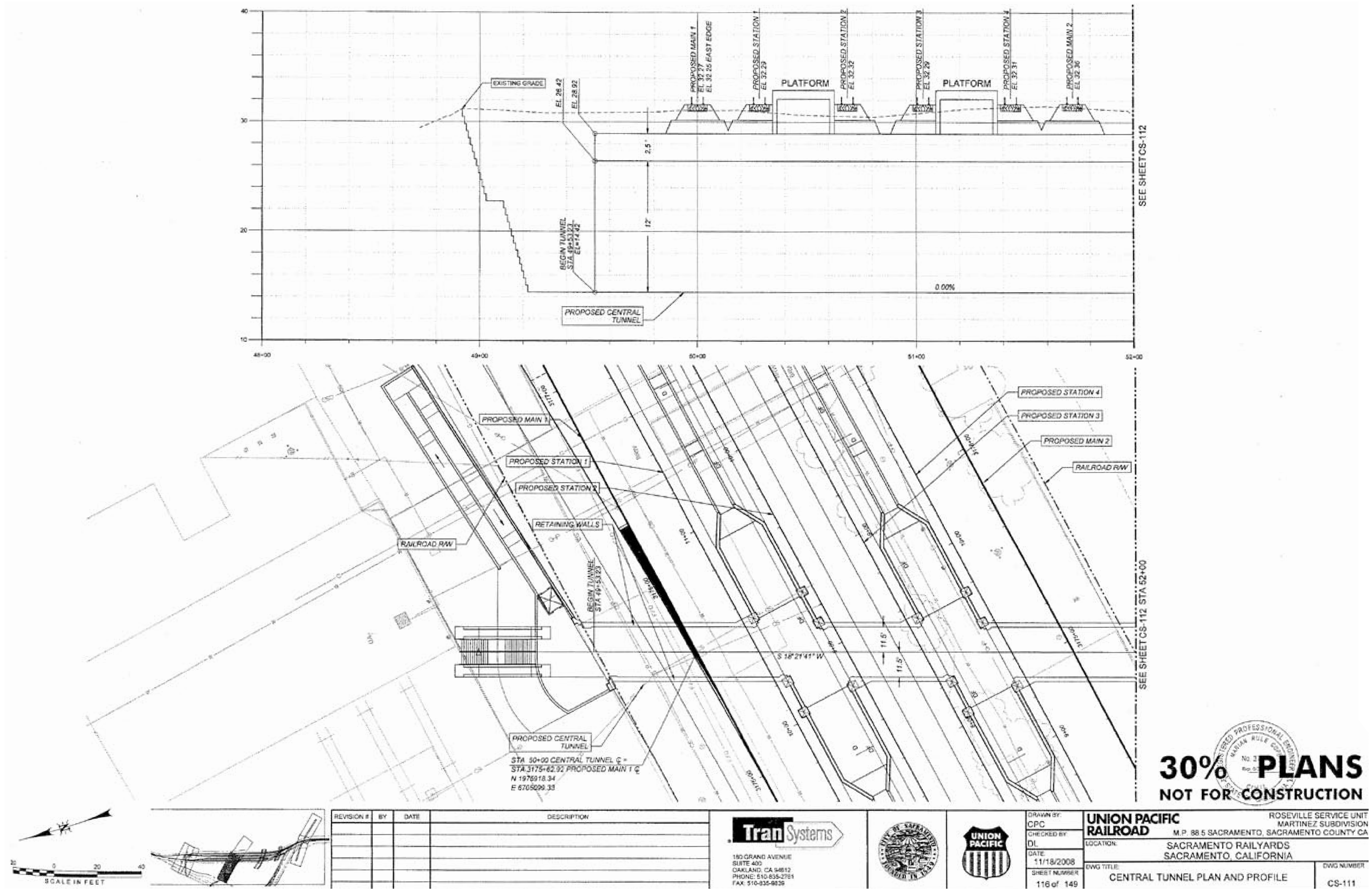


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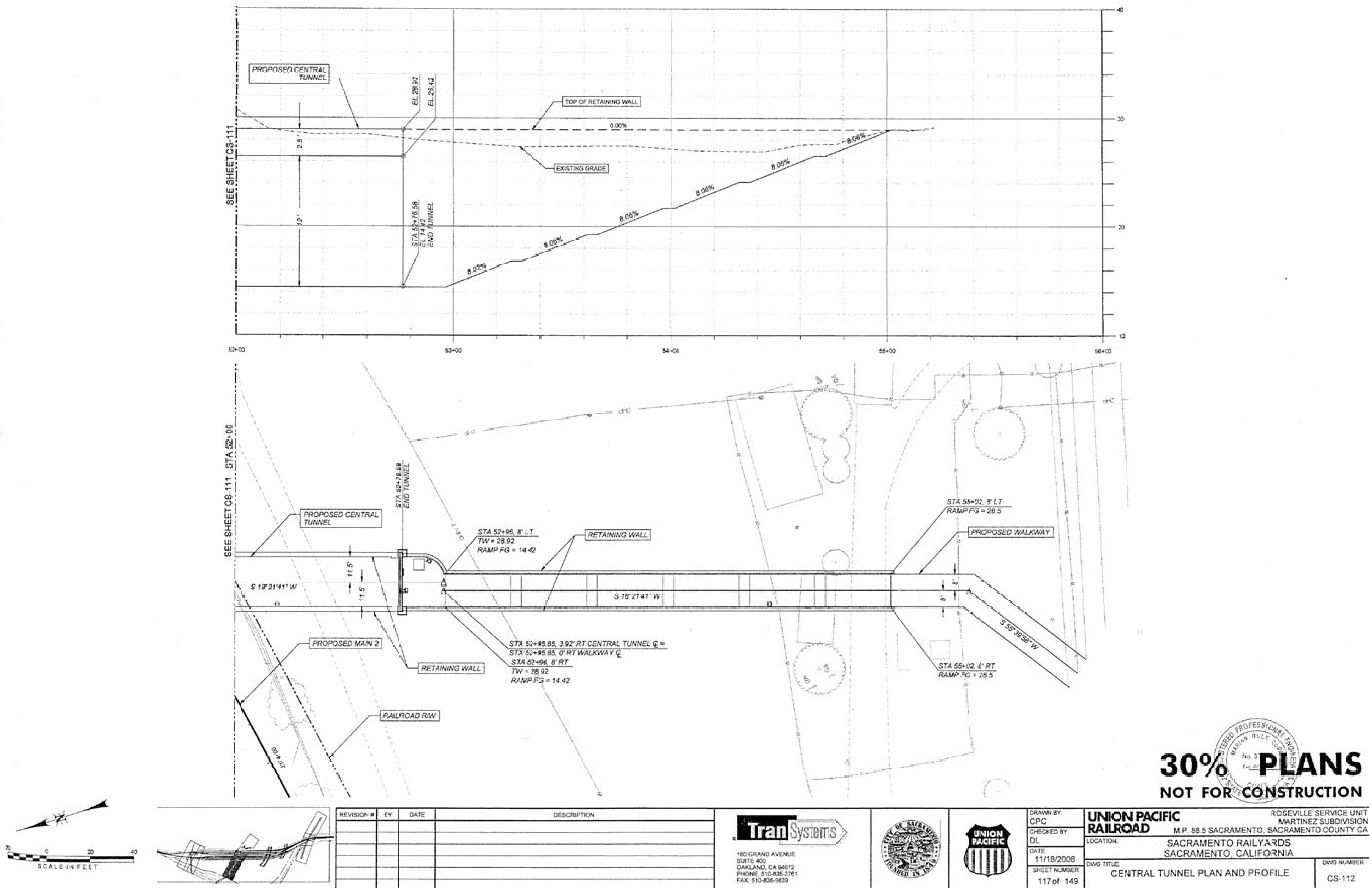
Figure 2-1e (page1)
Phase 1: Central Tunnel Plan and Profile



Source: Transystems 30% drawing

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Figure 2-1e (page 2)
Phase 1: Central Tunnel Plan and Profile

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Figure 2-2a
Phase 2 - Sacramento Valley Station Improvements

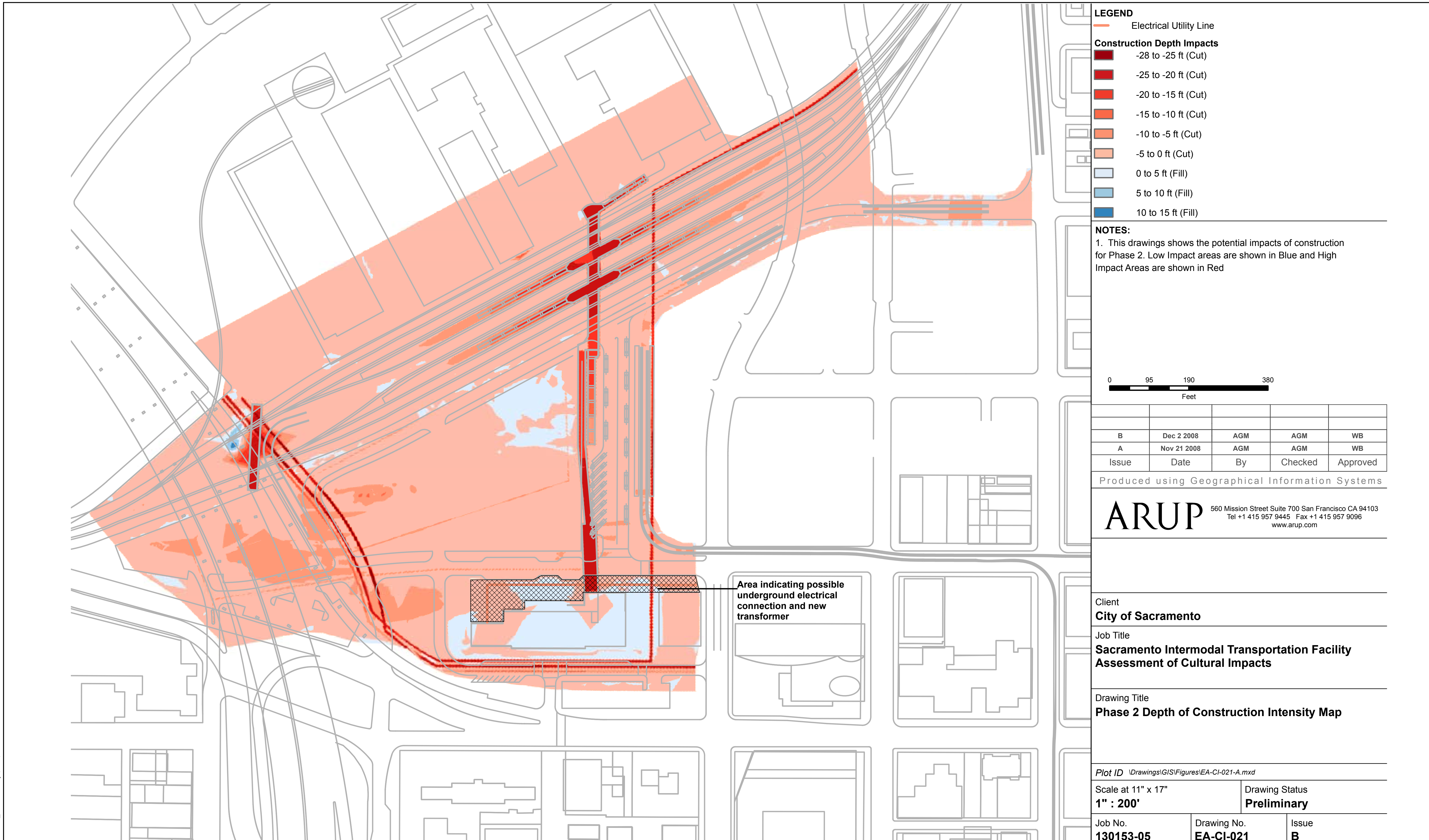

Figure 2-2b
Phase 2 Depth of Construction

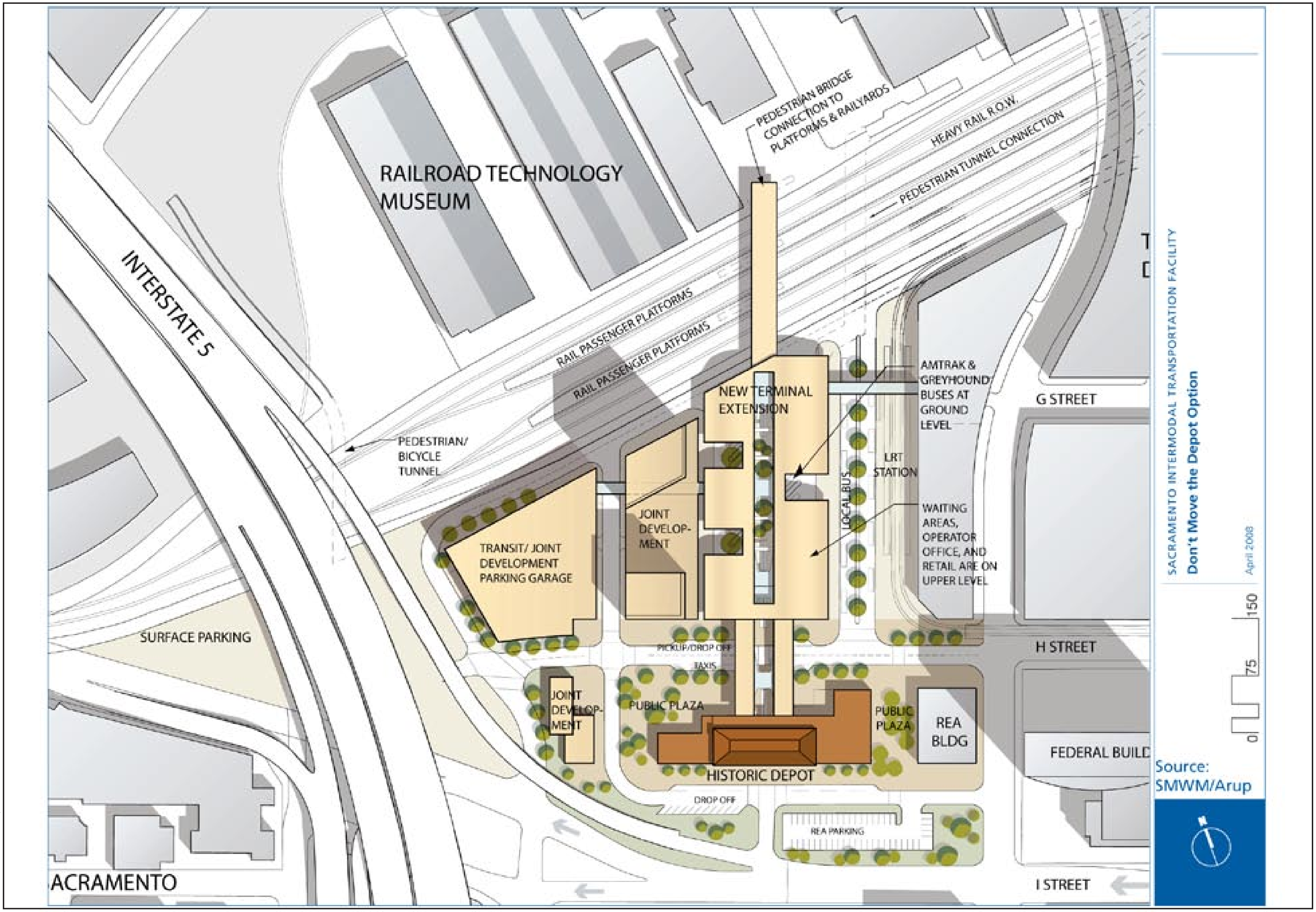

Figure 2-3
Phase 3 - Don't Move the Depot Option

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Figure 2-4
Phase 3 - Move the Depot Option

Chapter 3. Fundamentals of Noise and Vibration

The following is a brief discussion of fundamental noise and vibration concepts. For a detailed discussion, please refer to Caltrans' *Technical Noise Supplement* (TeNS) (Caltrans 1998), a technical supplement to the Protocol, which is available on Caltrans' website (http://www.dot.ca.gov/hq/env/noise/pub/tens_complete.pdf).

3.1. Sound, Noise, and Acoustics

Sound can be described as the mechanical energy of a vibrating object transmitted by pressure waves through a liquid or gaseous medium (e.g., air) to a hearing organ, such as a human ear. Noise is defined as loud, unexpected, or annoying sound.

In the science of acoustics, the fundamental model consists of a sound (or noise) source, a receiver, and the propagation path between the two. The loudness of the noise source and obstructions or atmospheric factors affecting the propagation path to the receiver determine the sound level and characteristics of the noise perceived by the receiver. The field of acoustics deals primarily with the propagation and control of sound.

3.2. Frequency

Continuous sound can be described by frequency (pitch) and amplitude (loudness). A low-frequency sound is perceived as low in pitch. Frequency is expressed in terms of cycles per second, or Hertz (Hz) (e.g., a frequency of 250 cycles per second is referred to as 250 Hz). High frequencies are sometimes expressed more conveniently in kilohertz (kHz), or thousands of Hertz. The audible frequency range for humans is generally between 20 Hz and 20,000 Hz.

3.3. Sound Pressure Levels and Decibels

The amplitude of pressure waves generated by a sound source determines the loudness of that source. Sound pressure amplitude is measured in micro-Pascals (mPa). One mPa is approximately one hundred billionth (0.00000000001) of normal atmospheric pressure. Sound pressure amplitudes for different kinds of noise environments can range from less than 100 to 100 million mPa. Because of this huge range of values, sound is rarely expressed in terms of mPa . Instead, a logarithmic scale is used to describe sound pressure level (SPL) in terms of decibels (dB). The threshold of hearing for young people is about 0 dB, which corresponds to 20 mPa.

3.4. Addition of Decibels

Because decibels are logarithmic units, SPL cannot be added or subtracted through ordinary arithmetic. Under the dB scale, a doubling of sound energy corresponds to a 3-dB increase. In other words, when two identical sources are each producing sound of the same loudness, the resulting sound level at a given distance would be 3 dB higher than one source under the same conditions. For example, if one automobile produces an SPL of 70 dB when it passes an observer, two cars passing simultaneously would not produce 140 dB—rather, they would combine to produce 73 dB. Under the dB scale, three sources of equal loudness together produce a sound level 5 dB louder than one source.

3.5. A-Weighted Decibels

The dB scale alone does not adequately characterize how humans perceive noise. The dominant frequencies of a sound have a substantial effect on the human response to that sound. Although the intensity (energy per unit area) of the sound is a purely physical quantity, the loudness or human response is determined by the characteristics of the human ear.

Human hearing is limited in the range of audible frequencies as well as in the way it perceives the SPL in that range. In general, people are most sensitive to the frequency range of 1,000–8,000 Hz and perceive sounds within that range better than sounds of the same amplitude in higher or lower frequencies. To approximate the response of the human ear, sound levels of individual frequency bands are weighted, depending on the human sensitivity to those frequencies. Then, an “A-weighted” sound level (expressed in units of A-weighted decibels [dBA]) can be computed based on this information.

The A-weighting network approximates the frequency response of the average young ear when listening to most ordinary sounds. When people make judgments of the relative loudness or annoyance of a sound, their judgments correlate well with the A-scale sound levels of those sounds. Other weighting networks have been devised to address high noise levels or other special problems (e.g., B-, C-, and D-scales), but these scales are rarely used in conjunction with highway-traffic noise. Noise levels for traffic noise reports are typically reported in terms of dBA. Table 3-1 describes typical A-weighted noise levels for various noise sources.

Table 3-1. Typical A-Weighted Noise Levels

Common Outdoor Activities	Noise Level (dBA)	Common Indoor Activities
	— 110 —	Rock band
Jet flyover at 1,000 feet		
	— 100 —	
Gas lawnmower at 3 feet		
	— 90 —	
Diesel truck at 50 feet at 50 mph		Food blender at 3 feet
	— 80 —	Garbage disposal at 3 feet
Noisy urban area, daytime		
Gas lawn mower, 100 feet	— 70 —	Vacuum cleaner at 10 feet
Commercial area		Normal speech at 3 feet
Heavy traffic at 300 feet	— 60 —	
		Large business office
Quiet urban daytime	— 50 —	Dishwasher next room
Quiet urban nighttime	— 40 —	Theater, large conference room (background)
Quiet suburban nighttime		
	— 30 —	Library
Quiet rural nighttime		Bedroom at night, concert
	— 20 —	
		Broadcast/recording studio
	— 10 —	
Lowest threshold of human hearing	— 0 —	Lowest threshold of human hearing

Source: Caltrans 1998.

3.6. Human Response to Changes in Noise Levels

As discussed above, doubling sound energy results in a 3-dB increase in sound. However, given a sound level change measured with precise instrumentation, the subjective human perception of a doubling of loudness will usually be different than what is measured.

Under controlled conditions in an acoustical laboratory, the trained, healthy human ear is able to discern 1-dB changes in sound levels, when exposed to steady, single-frequency (“pure-tone”) signals in the midfrequency (1,000–8,000 Hz) range. In typical noisy environments, changes in noise of 1–2 dB are generally not perceptible. However, it is widely accepted that people are able to begin to detect sound level increases of 3 dB in typical noisy environments. Further, a 5-dB increase is generally perceived as a distinctly noticeable increase, and a 10-dB increase is generally perceived as a doubling of loudness. Therefore, a doubling of sound energy (e.g., doubling the volume of traffic on a highway) that would result in a 3-dB increase in sound would generally be perceived as barely detectable.

3.7. Noise Descriptors

Noise in our daily environment fluctuates over time. Some fluctuations are minor, but some are substantial. Some noise levels occur in regular patterns, but others are random. Some noise levels fluctuate rapidly, but others slowly. Some noise levels vary widely, but others are relatively constant. Various noise descriptors have been developed to describe time-varying noise levels. The following are the noise descriptors used most commonly in traffic noise analysis.

- **Equivalent Sound Level (L_{eq}):** L_{eq} represents an average of the sound energy occurring over a specified period. In effect, L_{eq} is the steady-state sound level containing the same acoustical energy as the time-varying sound that actually occurs during the same period. The 1-hour A-weighted equivalent sound level (L_{eq}[h]) is the energy average of A-weighted sound levels occurring during a 1-hour period and is the basis for noise abatement criteria (NAC) used by Caltrans and FHWA.

- **Percentile-Exceeded Sound Level (L_{xx}):** L_{xx} represents the sound level exceeded for a given percentage of a specified period (e.g., L_{10} is the sound level exceeded 10% of the time, and L_{90} is the sound level exceeded 90% of the time).

- **Maximum Sound Level (L_{max}):** L_{max} is the highest instantaneous sound level measured during a specified period.

- **Day-Night Level (L_{dn}):** L_{dn} is the energy average of A-weighted sound levels occurring over a 24-hour period, with a 10-dB penalty applied to A-weighted sound levels occurring during nighttime hours between 10 p.m. and 7 a.m.

- **Community Noise Equivalent Level (CNEL):** Similar to L_{dn}, CNEL is the energy average of the A-weighted sound levels occurring over a 24-hour period, with a 10-dB penalty applied to A-weighted sound levels occurring during the nighttime hours between 10 p.m. and 7 a.m., and a 5-dB penalty applied to the A-weighted sound levels occurring during evening hours between 7 p.m. and 10 p.m.

3.8. Sound Propagation

When sound propagates over a distance, it changes in level and frequency content. The manner in which noise reduces with distance depends on the following factors.

3.8.1. Geometric Spreading

Sound from a localized source (i.e., a point source) propagates uniformly outward in a spherical pattern. The sound level attenuates (or decreases) at a rate of 6 dB for each doubling of distance from a point source. Highways consist of several localized noise sources on a defined path, and hence can be treated as a line source, which approximates the effect of several point sources. Noise from a line source propagates outward in a cylindrical pattern, often referred to as cylindrical spreading. Sound levels attenuate at a rate of 3 dB for each doubling of distance from a line source.

3.8.2. Ground Absorption

The propagation path of noise from a highway to a receiver is usually very close to the ground. Noise attenuation from ground absorption and reflective-wave canceling adds to the attenuation associated with geometric spreading. Traditionally, the excess attenuation has also been expressed in terms of attenuation per doubling of distance. This approximation is usually sufficiently accurate for distances of less than 200 feet. For acoustically hard sites (i.e., sites with a reflective surface between the source and the receiver, such as a parking lot or body of water), no excess ground attenuation is assumed. For acoustically absorptive or soft sites (i.e., those sites with an absorptive ground surface between the source and the receiver, such as soft dirt, grass, or scattered bushes and trees), an excess ground-attenuation value of 1.5 dB per doubling of distance is normally assumed. When added to the cylindrical spreading, the excess ground attenuation results in an overall drop-off rate of 4.5 dB per doubling of distance.

3.8.3. Atmospheric Effects

Receptors located downwind from a source can be exposed to increased noise levels relative to calm conditions, whereas locations upwind can have lowered noise levels. Sound levels can be increased at large distances (e.g., more than 500 feet) from the highway because of atmospheric temperature inversion (i.e., increasing temperature with elevation). Other factors such as air temperature, humidity, and turbulence can also have significant effects.

3.8.4. Shielding by Natural or Human-Made Features

A large object or barrier in the path between a noise source and a receiver can substantially attenuate noise levels at the receiver. The amount of attenuation provided by shielding depends on the size of the object and the frequency content of the noise source. Natural terrain features (e.g., hills and dense woods) and human-made features (e.g., buildings and walls) can substantially reduce noise levels. Walls are often constructed between a source and a receiver specifically to reduce noise. A barrier that breaks the line of sight between a source and a receiver will typically result in at least 5 dB of noise reduction. Taller barriers provide increased noise reduction. Vegetation between the highway and receiver is rarely effective in reducing noise because it does not create a solid barrier.

3.9. Fundamentals of Groundborne Noise and Vibration

Ground vibration is an oscillatory motion of the soil particles with respect to the equilibrium position that can be described in terms of displacement, velocity, or acceleration. Vibration can be described by its peak and root mean square (r.m.s.) amplitudes. The r.m.s amplitude is useful for assessing human annoyance, while peak vibration is used most often for assessing the potential for damage to buildings or structures, but it has also been used for assessing annoyance. In this report, groundborne vibration will be addressed in terms of the r.m.s. amplitude of the vibration.

Although vibration velocity is can be quantified in units of inches per second (in/sec), the dB notation is commonly used to describe vibration so as to cover the wide range of magnitudes that can be encountered. The vibration can be expressed in terms of the velocity level, in vibration decibels (VdB), defined as:

$$Lv = 20\log_{10}(v/v_{ref}), \text{ VdB}$$

Where: v = r.m.s velocity (in/sec)
V_{ref} = 1 micro-in/sec

Therefore, the descriptor used in this report to assess groundborne vibration is Lv referred to 1 micro-in/sec. Vibration is a function of the frequency of motion measured in cycles/second, or Hz. Ground vibration of concern for transportation sources generally spans 4–60 Hz. A graph of the level Lv vs. frequency is a spectral plot. For the level of analysis contained herein, the “overall” vibration is used. The overall vibration is the combined energy of ground motion at all frequencies.

Vibration attenuates as a function of the distance between the source and the receiver due to geometric spreading and inherent damping in the soil that absorbs energy of the ground motion. Groundbome vibration from rail transport systems is caused by dynamic forces at the wheel/rail interface. It is influenced by many factors, including the rail and wheel roughness, out-of-round wheel conditions, the mass and stiffness characteristics of the track support system, and the local soil conditions.

Vibration caused by the rail structure, such as at-grade ballast and tie track, radiates energy into the adjacent soil in the form of surface waves that propagate though the various soil and rock strata to the foundation of nearby buildings. Buildings respond differently to ground vibration depending on the type of foundation, mass of the building, and building interaction with the soil. Once inside the building, vibration propagates throughout the building with some attenuation with distance from the foundation, but often with amplification due to floor resonances. The basic concepts for rail system–generated ground vibration are illustrated in Figure 3-1.

Figure 3-2 illustrates the typical levels of human and structural response to groundborne vibration. The figure shows that the threshold of human perception is about 65 VdB, while the threshold for “cosmetic” structural damage is about 100 VdB (re: 1 micro-in/sec). However, the latter threshold, building damage is directly related to the condition of the structure. It is very rare that transportation-related ground vibration approaches building damage levels.

Groundborne noise is the radiated noise generated by vibrating building surfaces such as floors, walls, and ceilings. Groundborne noise is proportional to the vibration level and the absorption characteristics of the room. Therefore, the descriptor used in this report to assess groundborne noise is Lp referred to 20 mPa.

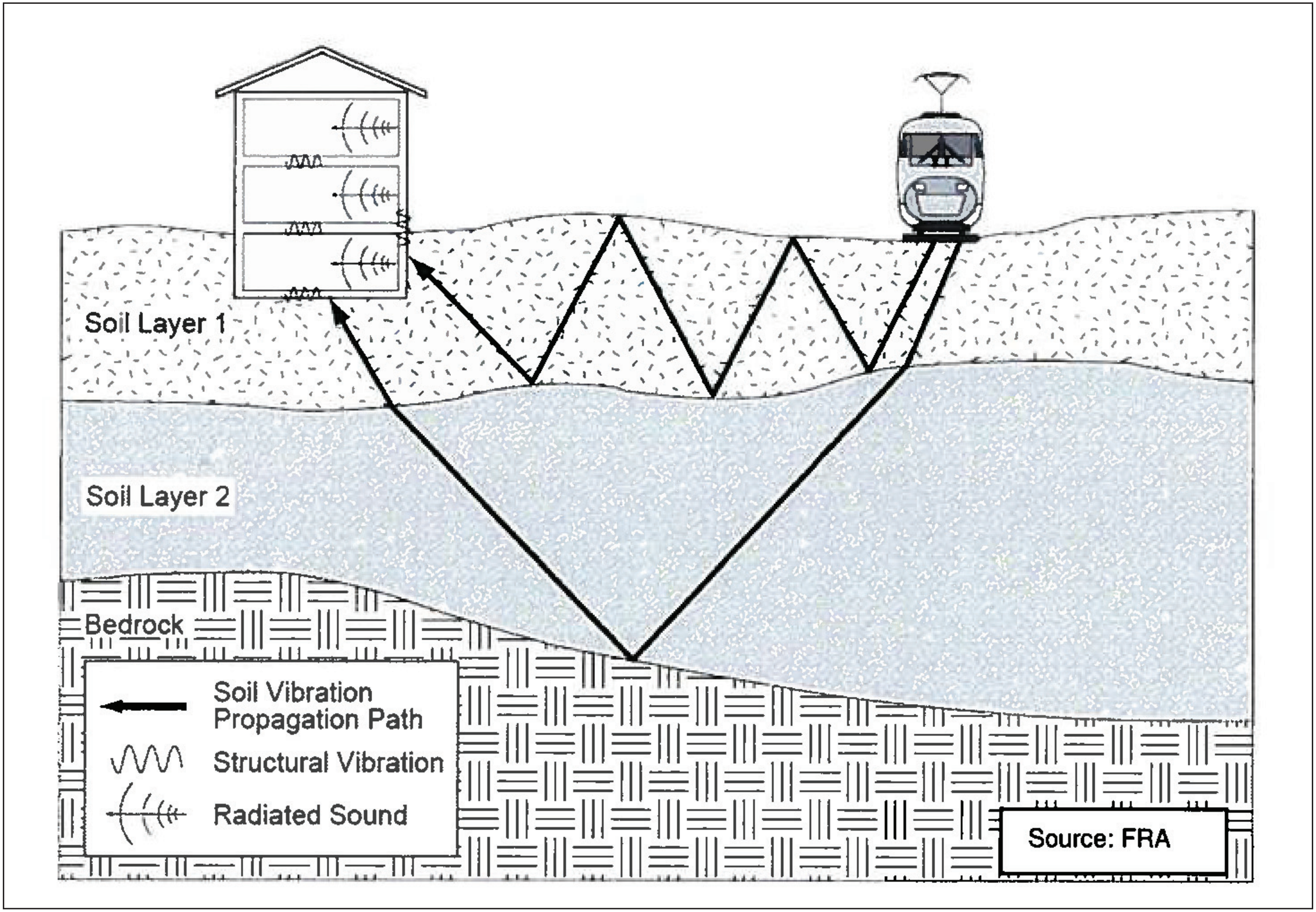

Figure 3-1
Propagation of Ground-Borne Vibration into Buildings

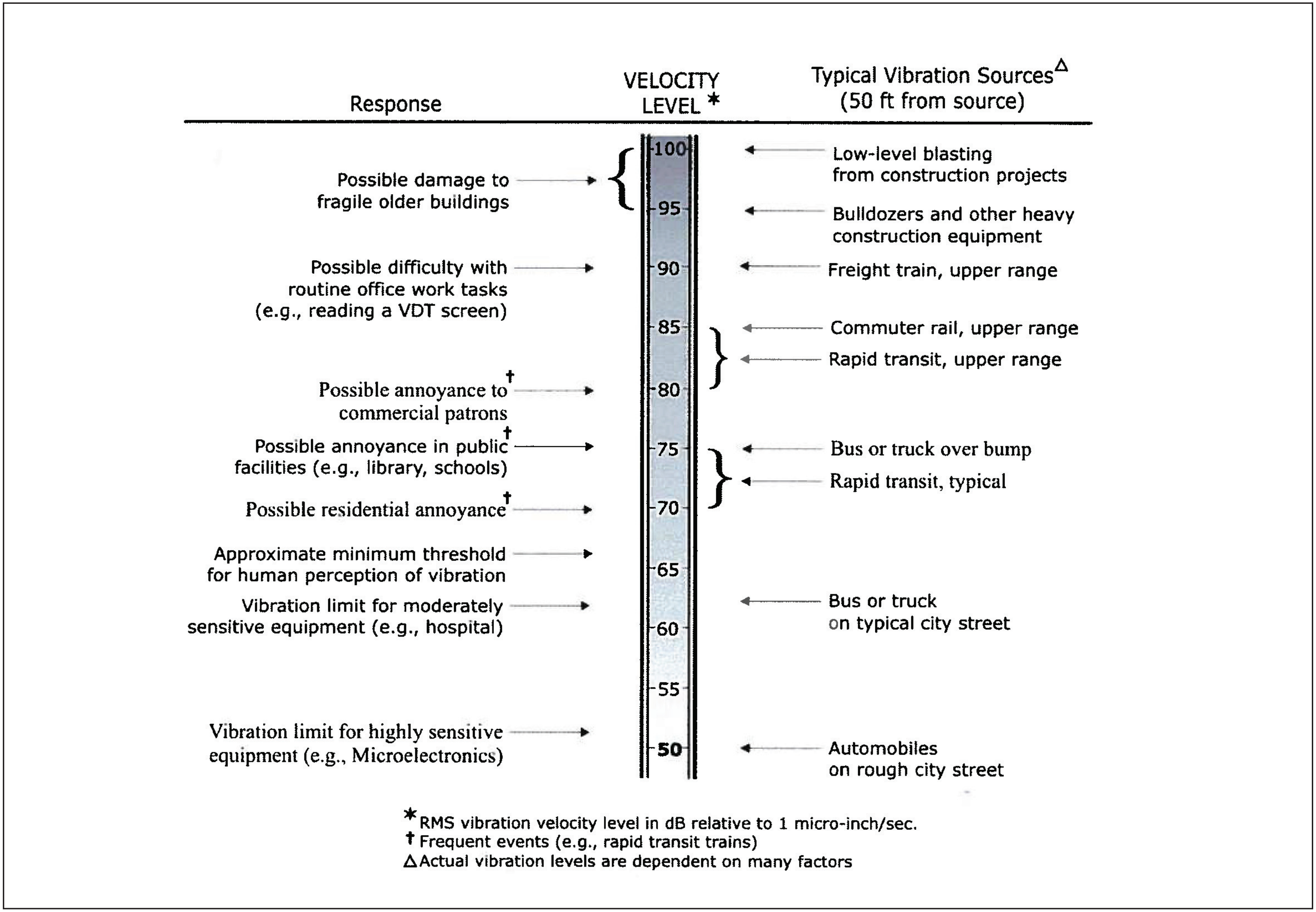

Figure 3-2
Typical Levels of Ground-Borne Vibration and Response to Vibration

Chapter 4. Regulations and Policies

This report focuses on the requirements of 23 CFR 772, as discussed below.

4.1. Federal Regulations and Policies

4.1.1. Highway Administration

23 CFR 772 provides procedures for preparing operational and construction noise studies and evaluating noise abatement considered for federal and federal-aid highway projects. Under 23 CFR 772.7, projects are categorized as Type I or II projects. FHWA defines a Type I project as a proposed federal or federal-aid highway project for the construction of a highway on a new location, or the physical alteration of an existing highway that significantly changes either the horizontal or vertical alignment or increases the number of through-traffic lanes. A Type II project is a noise barrier retrofit project that involves no changes to highway capacity or alignment.

Type I projects include those that create a completely new noise source, as well as those that increase the volume or speed of traffic or move the traffic closer to a receiver. Type I projects include the addition of an interchange, ramp, auxiliary lane, or truck-climbing lane to an existing highway, or the widening an existing ramp by a full lane width for its entire length. Projects unrelated to increased noise levels, such as striping, lighting, signing, and landscaping projects, are not considered Type I projects.

Under 23 CFR 772.11, noise abatement must be considered for Type I projects if the project is predicted to result in a traffic noise impact. In such cases, 23 CFR 772 requires that the project sponsor “consider” noise abatement before adoption of the final NEPA document. This process involves identification of noise abatement measures that are reasonable, feasible, and likely to be incorporated into the project, and identification of noise impacts for which no apparent solution is available.

Traffic noise impacts, as defined in 23 CFR 772.5, occur when the predicted noise level in the design year approaches or exceeds the NAC specified in 23 CFR 772 or when a predicted noise level substantially exceeds the existing noise level (a “substantial” noise increase). 23 CFR 772 does not specifically define the terms “substantial increase” or “approach”; these criteria are defined in the Protocol, as described below.

Table 4-1 summarizes NAC corresponding to various land use activity categories. Activity categories and related traffic noise impacts are determined based on the actual land use in a given area.

Table 4-1. Activity Categories and Noise Abatement Criteria

Activity Category	NAC, Hourly A-Weighted Noise Level (dBA-L_{eq}[h])	Description of Activities
A	57—Exterior	Lands on which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose
B	67—Exterior	Picnic areas, recreation areas, playgrounds, active sport areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals
C	72—Exterior	Developed lands, properties, or activities not included in Activity Categories A or B above
D	–	Undeveloped lands
E	52—Interior	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums

In identifying noise impacts, primary consideration is given to exterior areas of frequent human use. In situations where there are no exterior activities or where the exterior activities are far from the roadway or physically shielded in a manner that prevents an impact on exterior activities, the interior criterion (Activity Category E) is used as the basis for determining a noise impact.

Because there are no off-site roadway improvements included in the proposed project, the proposed project is not a Type I project. Accordingly, no evaluation of operational traffic noise is required under 23 CFR 772.

4.1.2. Federal Transit Administration/Federal Railroad Administration

FTA's environmental impact regulation is codified in 23 CFR 771. FTA 2006 provides guidance for noise and vibration impact assessment. FRA criteria and methodology for noise and vibration are similar to the FTA criteria and methodology for noise and vibration.

4.1.2.1. NOISE IMPACT CRITERIA

FTA defines noise impact criteria based on three land use categories. Table 4-2 describes these three land use categories.

Table 4-2. Land Use Categories and Metrics for Transit Noise Impact Criteria

Land Use Category	Noise Metric (dBA)	Description of Land Use Category
1	Outdoor L_{eq}(h)*	Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.
2	Outdoor L_{dn}	Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor L_{eq}(h)*	Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation, and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds, and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.

Source: FTA 2006.
* L_{eq} for the noisiest hour of transit-related activity during hours of noise sensitivity.

FTA categorizes noise impacts into the following three categories

- **No Impact—**On average, the introduction of the project will result in an insignificant increase in the number of people highly annoyed by the new project-related noise.

- **Moderate Impact—**An impact where the project-related change in noise is noticeable to most people, but may not be sufficient to cause strong, adverse reactions from the community.

- **Severe Impact—**An impact where a significant percentage of people would be highly annoyed by the new noise (i.e., the project-related increase in noise).

Table 4-3 summarizes FTA noise impact criteria for each land use category.

Table 4-3. Noise Levels Defining Impact for Transit Projects

Existing Noise Exposure, L_{eq}(h) or L_{dn} (dBA)*	Project Noise Impact Exposure, L_{eq}(h) or L_{dn} (dBA)*					
	Category 1 or 2 Sites			Category 3 Sites		
	No Impact	**Moderate Impact**	**Severe Impact**	**No Impact**	**Moderate Impact**	**Severe Impact**
<43	<Ambient+10	Ambient + 10 to 15	>Ambient+15	<Ambient+15	Ambient + 15 to 20	>Ambient+20
43	<52	52–58	>58	<57	57-63	>63
44	<52	52–58	>58	<57	57-63	>63
45	<52	52–58	>58	<57	57-63	>63
46	<53	53–59	>59	<58	58-64	>64
47	<53	53–59	>59	<58	58-64	>64
48	<53	53–59	>59	<58	58-64	>64
49	<54	54–59	>59	<59	59-64	>64
50	<54	54–59	>59	<59	59-64	>64
51	<54	54–60	>60	<59	59-65	>65
52	<55	55–60	>60	<60	60-65	>65
53	<55	55–60	>60	<60	60-65	>65
54	<55	55–61	>61	<60	60-66	>66
55	<56	56–61	>61	<61	61-66	>66
56	<56	56–62	>62	<61	61-67	>67
57	<57	57–62	>62	<62	62-67	>67
58	<57	57–62	>62	<62	62-67	>67
59	<58	58–63	>63	<63	63-68	>68
60	<58	58–63	>63	<63	63-68	>68
61	<59	59–64	>64	<64	64-69	>69
62	<59	59–64	>64	<64	64-69	>69
63	<60	60–65	>65	<65	65-70	>70
64	<61	61–65	>65	<66	66-70	>70
65	<61	61–66	>66	<66	66-71	>71
66	<62	62–67	>67	<67	67-72	>72
67	<63	63–67	>67	<68	68-72	>72
68	<63	63–68	>68	<68	68-73	>73
69	<64	64–69	>69	<69	69-74	>74
70	<65	65–69	>69	<70	70-74	>74
71	<66	66–70	>70	<71	71-75	>75
72	<66	66–71	>71	<71	71-76	>76
73	<66	66–71	>71	<71	71-76	>76
74	<66	66–72	>72	<71	71-77	>77
75	<66	66–73	>73	<71	71-78	>78
76	<66	66–74	>74	<71	71-79	>79
77	<66	66–74	>74	<71	71-79	>79
>77	<66	66–75	>75	<71	71-80	>80

Source: FTA 2006.

* L_{dn} is used for land use where nighttime sensitivity is a factor; L_{eq} during the hour of maximum transit noise exposure is used for land use involving only daytime activities.

Figure 4-1 expresses these criteria in terms of the project-related increase in noise for Category 1 and 2 land uses.

Historically significant sites are treated as noise-sensitive depending on the land use activities. Sites of national significance with considerable outdoor use required for site interpretation would be in Category 1. Historical sites that are currently used as residences will be in Category 2. Historic buildings with indoor use of an interpretive

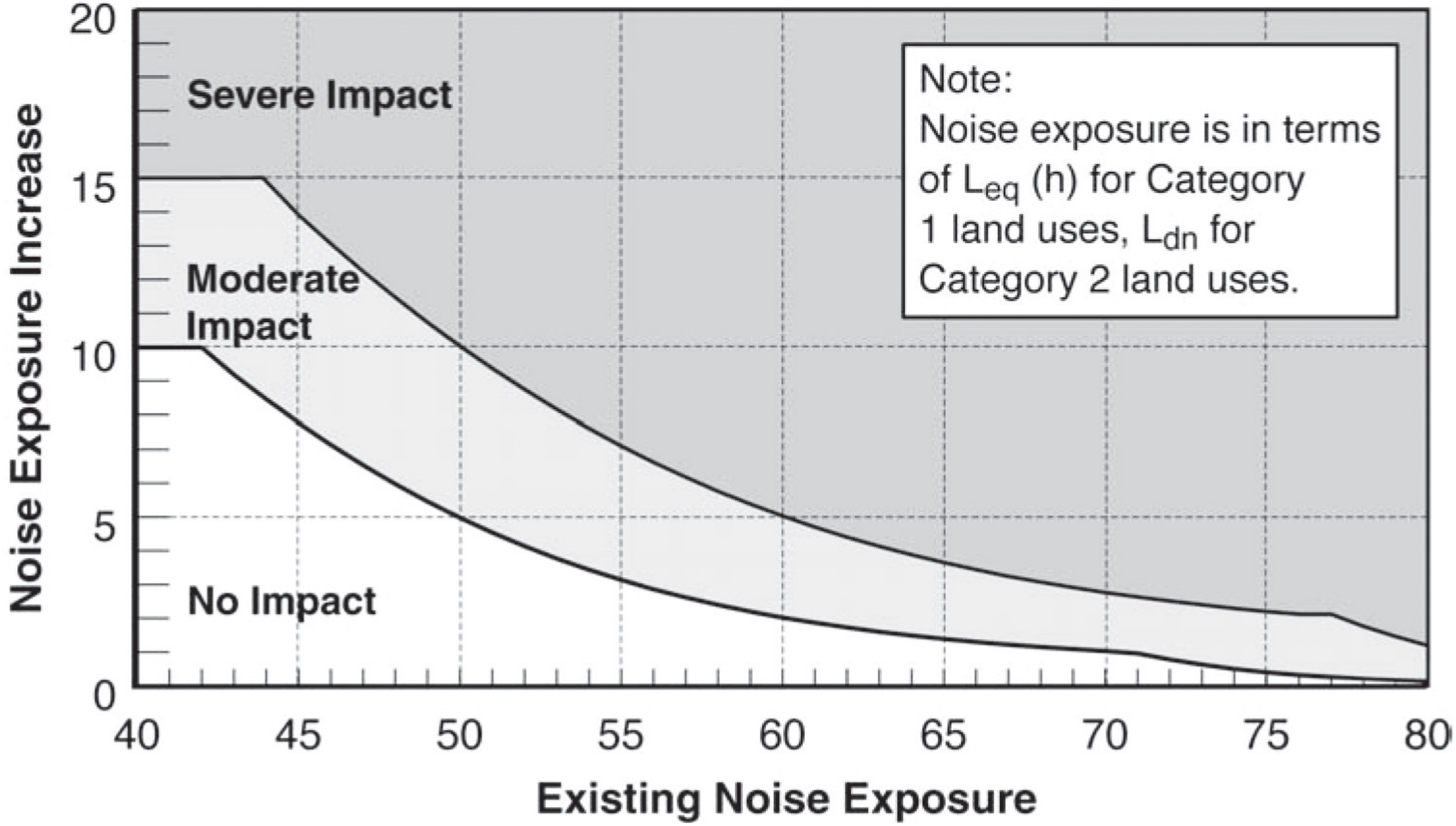

Figure 4-1
Increase in Cumulative Noise Levels Allowed by Criteria (Land Use Cat. 1 & 2)

nature involving meditation and study fall into Category 3. These include museums, significant birthplaces, and buildings in which significant historical events occurred.

Most busy downtown areas have buildings that are historically significant because they represent a particular architectural style or are prime examples of the work of an historically significant designer. If the buildings or structures are used for commercial or industrial purposes and are located in busy commercial areas, they are not considered noise-sensitive and the noise impact criteria do not apply. Similarly, historical transportation structures, such as terminals and railroad stations, are not considered noise-sensitive land uses themselves. These buildings or structures are, of course, afforded special protection under Section 4(f) of the Department of Transportation Act and Section 106 of the National Historic Preservation Act. However, based strictly on how they are used and the settings in which they are located, these types of historical buildings are not considered noise-sensitive sites.

Special protection provided by Section 4(f) of the Department of Transportation Act and Section 106 of the National Historic Preservation Act come into play frequently during the environmental review of transit projects. Section 4(f) protects historic sites and publicly owned parks, recreation areas, and wildlife refuges. Section 106 protects historic and archeological resources. In general, noise in the Moderate Impact range would not substantially impair the use of a property afforded protection under Section 4(f). Therefore, it would not constitute a “constructive use” as this term is defined in Section 4(f) regulations. In the Section 106 process protecting historic and cultural properties, Moderate Impact may or may not be considered an “adverse effect” depending on the individual circumstances. Historic properties are only noise-sensitive based on how they are used. As previously noted, some historic properties are not noise-sensitive at all. It is possible, though, that a historic building housing sensitive uses like a library or museum could be affected adversely by noise in the Moderate range. The regulatory processes stemming from these statutes require coordination and consultation with agencies and organizations having jurisdiction over these resources. Their views on the project's impact on protected resources are given careful consideration by FTA and the project sponsor, and their recommendations may influence the decision to adopt noise reduction measures.

Mitigation is not required when project-generated noise is in the No Impact range. Noise impacts in the Severe range represent the most compelling need for mitigation. If it is not practical to avoid Severe Impacts by changing the location of the project, mitigation must be considered. Impacts in this range have the greatest adverse impact, and there is a presumption by FTA that mitigation will be incorporated into the project unless there are truly extenuating circumstances that prevent it. Projected noise levels in the Moderate Impact range will also require consideration of mitigation and adoption of mitigation when it is considered reasonable. Refer to FTA 2006 for a detailed discussion of mitigation requirements.

4.1.2.2. VIBRATION IMPACT CRITERIA

FTA defines vibration impact criteria based on three land use types:

- **Category 1—**Buildings where vibration would interfere with operations within the building, including levels that may be well below those associated with human annoyance.
- **Category 2—**All residential land uses and any buildings where people sleep, such as hotels and hospitals.
- **Category 3—**Schools, churches, other institutions, and quiet offices that do not have vibration-sensitive equipment, but still have the potential for activity interference.

Table 4-4 summarizes FTA impact criteria for groundborne vibration and noise.

Table 4-4. Groundborne Vibration and Noise Impact Criteria for General Assessment

Land Use Category	Groundborne Vibration Impact Levels (VdB re 1 micro-in/sec)			Groundborne Noise Impact Levels (dB re 20 mPa)		
	Frequent Events[a]	Occasional Events[b]	Infrequent Events[c]	Frequent Events[a]	Occasional Events[b]	Infrequent Events[c]
Category 1: Buildings where vibration would interfere with interior operations	65 VdB[d]	65 VdB[d]	65 VdB[d]	N/A[d]	N/A[d]	N/A[d]
Category 2: Residences and buildings where people normally sleep	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

Source: FTA 2006.

[a] "Frequent" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.

[b] "Occasional" is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.

[c] "Infrequent" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.

[d] This criterion limit is based on levels that are acceptable for most moderately sensitive equipment, such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.

[e] Vibration-sensitive equipment is generally not sensitive to groundborne noise.

There are some buildings, such as concert halls, television and recording studios, and theaters, that can be very sensitive to vibration and noise, but do not fit into any of the three categories. Table 4-5 gives criteria for acceptable levels of groundborne vibration and noise for various types of special buildings.

Table 4-5. Groundborne Vibration and Noise Impact Criteria for Special Buildings

Type of Building or Room	Groundborne Vibration Impact Levels (VdB re 1 micro-in/sec)		Groundborne Noise Impact Levels (dB re 20 mPA)	
	Frequent[a] Events	Occasional or Infrequent[b] Events	Frequent[a] Events	Occasional or Infrequent[b] Events
Concert halls	65 VdB	65 VdB	25 dBA	25 dBA
TV studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theaters	72 VdB	80 VdB	35 dBA	43 dBA

Source: FTA 2006.

[a] "Frequent" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.

[b] "Occasional or Infrequent" is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.

[c] If the building will rarely be occupied when the trains are operating, there is no need to consider impacts. As an example, consider locating a commuter rail line next to a concert hall. If no commuter trains will operate after 7 p.m., it should be rare that the trains interfere with the use of the hall.

The criteria in Tables 4-4 and 4-5 are related to groundborne vibration causing human annoyance or interfering with use of vibration-sensitive equipment. It is extremely rare for vibration from train operations to cause any sort of building damage, even minor cosmetic damage. However, there is sometimes concern about damage to fragile historic buildings located near the right-of-way. Even in these cases, damage is unlikely except when the track will be very close to the structure.

To assess the potential for vibration damage to fragile historic buildings, FTA applies thresholds developed for assessing vibration impacts from construction equipment. Table 4-6 summarizes these criteria.

Table 4-6. Construction Vibration Damage Criteria

Building Category	PPV (in/sec)	Approximate Lv*
I. Reinforced-concrete, steel or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage	0.12	90

Source: FTA 2006.
* r.m.s. velocity in decibels (VdB) re 1 micro-in/sec.

4.2. State Regulations and Policies

4.2.1. Traffic Noise Analysis Protocol for New Highway Construction and Reconstruction Projects

The Protocol specifies the policies, procedures, and practices to be used by agencies that sponsor new construction or reconstruction of federal or federal-aid highway projects. The NAC specified in the Protocol are the same as those specified in 23 CFR 772. The Protocol defines a noise increase as substantial when the predicted noise levels with project implementation exceed existing noise levels by 12 dBA. The Protocol also states that a sound level is considered to approach an NAC level when the sound level is within 1 dB of the NAC identified in 23 CFR 772 (e.g., 66 dBA is considered to approach the NAC of 67 dBA, but 65 dBA is not).

As discussed above, there are no off-site roadway improvements included in the proposed project. Accordingly, the proposed project is not a Type I project and no evaluation of operational traffic noise is required under 23 CFR 772.

Chapter 5. Study Methods and Procedures

This report is based primarily on technical noise and vibration analyses presented in the following two reports:

- *Sacramento Railyards Specific Plan Environmental Vibration Impact Assessment Technical Report*, dated June 2007 (WIA 2007)

- *Railyards Specific Plan Draft Environmental Impact Report*, dated August 2007 (City of Sacramento 2007)

5.1. Methods for Identifying Land Uses and Selecting Noise Measurement and Modeling Receiver Locations

Because the proposed project is not a Type I project under 23 CFR 772, the focus of the assessment is land use designations applied by FTA. Noise- and vibration-sensitive land uses in the project area were identified through field investigations and review of land use mapping.

5.2. Field Measurement Procedures

A field noise study was conducted to quantify existing noise conditions in the project area. The following is a summary of the procedures used to collect short- and long term sound level data.

5.2.1. Field Measurements

Existing noise levels were measured using a Larson-Davis Model 720 precision sound level meter, which satisfies the American National Standards Institute for general environmental noise measurement instrumentation. Short-term (15-minute) ambient daytime noise levels were measured in and around the project area at six locations on May 3, 2007. Two 24-hour measurements were also taken on March 28–29, 2007, and April 3–4, 2007.

5.3. Noise and Vibration Prediction Methods

Because the proposed project is not a Type I project as defined in 23 CFR 772, a detailed traffic noise impact analysis in accordance with the requirements of 23 CFR 772 has not been conducted. However, a discussion of the effects of Phase 1 and 2 development on traffic noise and modeled traffic noise levels predicted under existing conditions and cumulative conditions (i.e., Phase 3 conditions) with and without the project are discussed to provide context for the noise environment under existing and future conditions.

Traffic noise levels were predicted using the FHWA Traffic Noise Model Version 2.5 (TNM 2.5) and traffic data provided by the project traffic engineer. TNM 2.5 is a computer model based on two FHWA reports: FHWA-PD-96-009 and FHWA-PD-96-010 (FHWA 1998a, 1998b). Key inputs to the traffic noise model include the locations of roadways, shielding features (e.g., topography and buildings), noise barriers, ground type, and receivers.

Noise and vibration levels from construction and modifications to the rail alignment were evaluated using methods described in FTA 2006.

5.4. Methods for Identifying Noise and Vibration Impacts

Because the proposed project is not a Type I project as defined in 23 CFR 772, a detailed traffic noise impact analysis in accordance with the requirements of 23 CFR 772 has not been conducted. Noise and vibration impacts from construction and modifications to the rail alignment were evaluated using methods and impact criteria described in FTA 2006.

Chapter 6. Existing Noise Environment

6.1. Existing Land Uses

The proposed project would be developed on land historically used as a major train station and locomotive works. The project area is surrounded by urban uses (Figure 1-2). Office buildings and retail, commercial, industrial, and residential uses predominate in the vicinity of the site. Residential uses exist south and southeast of the project border, with the Alkali Flat residential neighborhood abutting the southeastern portion of the project area. There are also limited residential uses as well as industrial, office, commercial, and a number of social service enterprises north of the project area within the Richards Boulevard Area.

6.2. Noise Measurement Results

The existing noise environment in the project area is characterized below based on short- and long-term noise monitoring that was conducted.

6.2.1. Short-Term Monitoring

Table 6-1 summarizes the results of the short-term noise monitoring conducted in the project area. Refer to Figure 6-1 for the location of measurement positions.

Table 6-1. Existing Daytime Noise Levels at Selected Locations

Noise Measurement Location	Distance from Centerline (feet)	Primary Noise Sources	Measured Noise Levels 15-minute L_{eq} (dBA)
#3 – In front of 517 7th Street	42	Roadway noise from 7th Street	63.4
#4 – In front of 619 12th Street	38	Roadway noise from 12th Street, light rail along 12th Street	68.1
#5 – In front of Econo Lodge (along 16th Street)	45	Roadway noise from 16th Street	69.5
#6 – In front of 1239 Richards Boulevard	96	Roadway noise from Richards Boulevard	63.7
#7 – In front of residential units at B Street and Bannon Street	23	Roadway noise from Bannon Street	60.6
#8 – Along 7th Street near inactive railroad spur within the Specific Plan Area	28	Roadway noise from 7th Street	67.4

Source: PBS&J/EIP 2007 in City of Sacramento 2007.
Notes: Noise levels measure on May 3, 2007 during mid-day hours (between about 10:30 a.m. and 3:00 p.m.).

6.2.2. Long-Term Monitoring

Table 6-2 summarizes the results of long-term monitoring conducted in the project area.

Table 6-2. Existing 24-Hour Noise Levels at Selected Locations

Noise Measurement Location	Primary Noise Sources	Noise Level Statistics (dBA)			
		24-hour Average L_{eq}	Calculated L_{dn}	L_{min}	L_{max}
#1 – 500 feet from I-5 within Specific Plan Area	Roadway noise from I-5	67.4	72.4	49.0	88.7
#2 – 150 feet from UPRR alignment within Specific Plan Area	Freight train and commuter rail passbys	63.7	71.8	46.4	100.1

Source: PBS&J/EIP 2007 in City of Sacramento 2007.

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Figure 6-1
Noise Monitoring Locations

Chapter 7. Future Noise and Vibration Environment, Impacts, and Mitigation

7.1. Future Noise Environment, Impacts, and Mitigation

Because the proposed project is not a Type I project as defined in 23 CFR 772, a detailed traffic noise impact analysis in accordance with the requirements of 23 CFR 772 has not been conducted. However, a discussion of the effects of Phase 1 and Phase 2 development on traffic noise and modeled traffic noise levels predicted under existing conditions and cumulative conditions (i.e. Phase 3 conditions), with and without the project, are discussed to provide context for the noise environment under existing and future conditions.

7.1.1. Phase 1

Under Phase 1, the existing mainline freight and passenger tracks would be realigned. There would be some other facility improvements made at this time. None of these activities would affect trip generation or traffic patterns and would therefore have no effect on traffic noise.

Realignment of the track will move the track away from developed land uses located to the south and east of the project site. Increasing the distance between the tracks and adjacent land uses will reduce train noise. However, the straightening of the track will allow trains to travel faster through the area which will have the opposite effect of increasing noise.

TNM 2.5 was used to model the effect of the track geometry change on noise. For the purposes of assessing the effect of increased speed existing trains speeds are assumed to be 10 miles per hour (mph) and speeds with the straightened track are assumed to be 30 mph. This is consistent with the assumption used in the vibration analysis report (WIA 2007). As recommended in FTA 2006 speed is assumed to increase noise accordingly to the following equation:

$$\text{Increase in noise} = 20\log_{10}(S_2/S_1)$$

Where: S_1 = initial speed

S_2 = increased speed

Increasing the speed from 10 to 30 mph therefore would be predicted to increase noise by about 9 dB.

Table 7-1 summarizes noise predictions associated with straightening the track and the increased speed. Figure 7-1 shows the noise prediction points.

Table 7-1. Predicted Train Noise Levels (L_{dn})

Receiver	Land Use	FTA Category	Existing Alignment L_{dn} (10 mph)	New Alignment L_{dn} (30 mph)	Increase	Impact
1	Residence	2	67	65	-2	No impact
2	Residence	2	69	77	+8	Severe
3	Apartment	2	72	81	+9	Severe
4	Apartment	2	67	76	+9	Severe
5	Apartment	2	63	71	+8	Severe

The results in Table 7-1 indicate that severe noise impacts are predicted to occur at residential uses located east of the project site as a result of the increase train speeds associated with straightening the track.

Table 7-2 shows the increases in noise allowed under FTA criteria that correspond to the Moderate and No Impact levels. It also shows the reduction in noise that would be needed to reduce noise impacts to the Moderate and No Impact levels.

Table 7-2. Increases Allowed for FTA Moderate and No-Impact Levels

Receiver	Land Use	FTA Category	Existing Alignment L_{dn} (10 mph)	Increase for No Impact	Increase for Moderate Impact	Mitigation Needed for No Impact	Mitigation Needed for Moderate Impact
1	Residence	2	67	1 dB	3 dB	0 dB	0 dB
2	Residence	2	69	1 dB	3 dB	-7 dB	-5 dB
3	Apartment	2	72	1 dB	2 dB	-8 dB	-7 dB
4	Apartment	2	67	1 dB	3 dB	-8 dB	-6 dB
5	Apartment	2	63	2 dB	4 dB	-6 dB	-4 dB

There are two possible forms of mitigation this impact. The first would be to limit train speeds. To achieve the No Impact level, train speeds would be need to be limited such that the existing noise level is not increased by more than about 1 dB. This means that the existing 10 mph speeds could not increase to more than about 11 mph. To achieve the Moderate Impact level, train speeds would be need to be limited such that the existing noise level is not increased by more than about 2 dB. This means that the existing 10 mph speeds could not increase to more than about 13 mph.

The second form of mitigation would be to construct a barrier along the south side of the track. The barrier would likely need to be 12 to 14 feet above the track elevation and

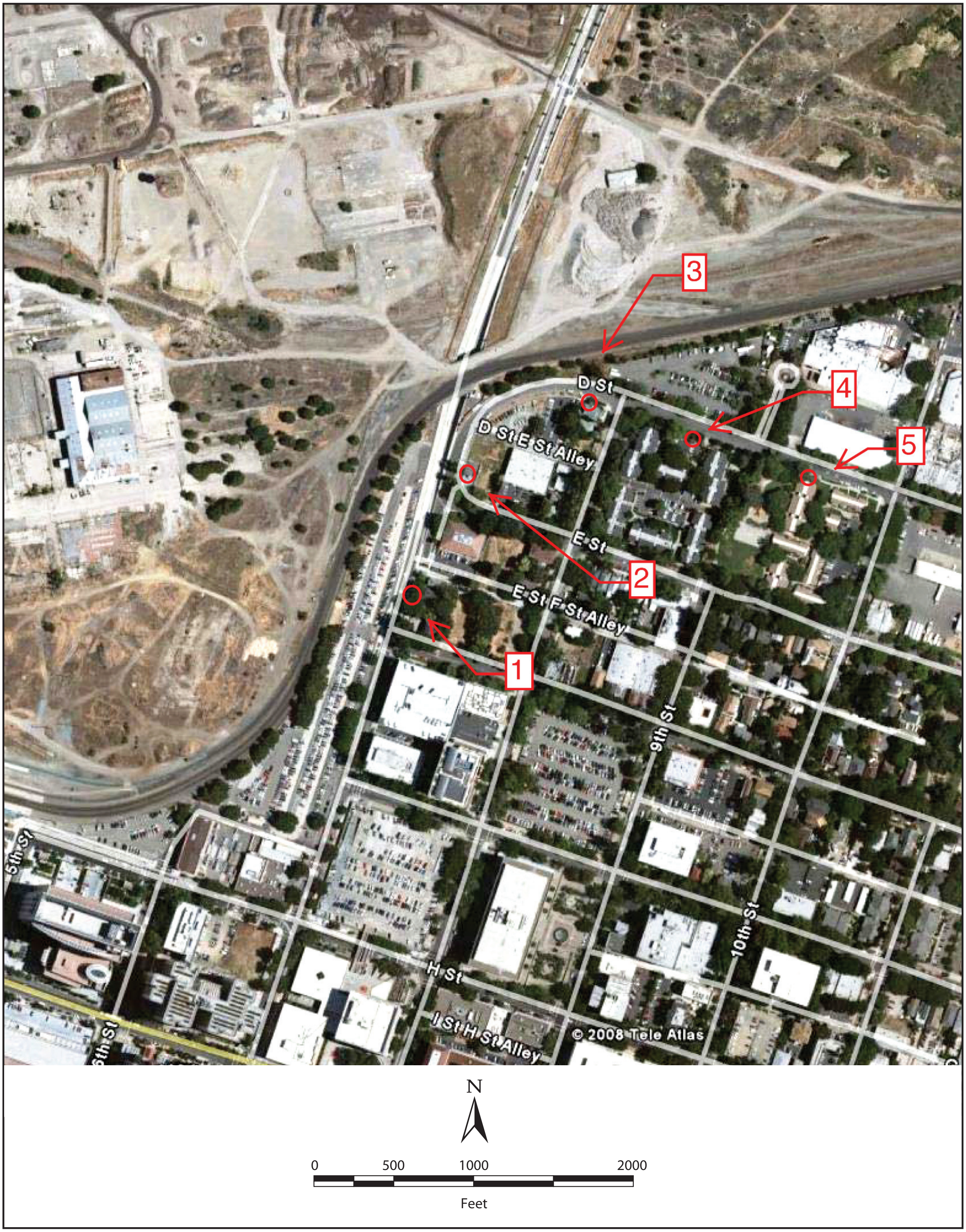

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Figure 7-1
Train Noise Modeling Locations

extend from the project site to the location on the track where trains are currently able achieve 30 mph.

This analysis also indicates that the buildings in the Central Shops District could be exposed to noise in excess of 80 dB-L_{eq} from train passages. These buildings are currently unoccupied and are not used for any noise sensitive activities. However, in the future there are plans to develop these buildings for commercial uses and a museum. Because these buildings would not be developed before the track is realigned, the increased noise from the track realignment is not predicted to result in an adverse effect on these buildings. The future reuse of the buildings, however, will need to take into account the high noise levels from train passages.

7.1.2. Phase 2

Under Phase 2, additional facility improvements would be made including relocating and reconfiguring passenger parking to accommodate existing parking demand and to improve the drop-off area in front of the Depot. The traffic analysis conducted for this phase indicate that very small changes in peak hour traffic volumes (typically less than 10%) will occur at some intersections in the area. A 10% change in traffic volume equates to less than a 0.5-dB change in traffic noise, which would not be perceptible.

7.1.3. Phase 3

Under the Phase 3, alternatives the existing Station would be converted into a large, multimodal regional transportation facility with substantially expanded facilities. The primary difference between the two alternatives is the ultimate location of the Depot building. A detailed traffic analysis of Phase 3 conditions has not been prepared. However, the cumulative traffic noise conditions evaluated for the Railyards Specific Plan (City of Sacramento 2007) are representative of conditions that would occur under Phase 3. Table 7-3 summarizes traffic noise modeling results under cumulative conditions with and without implementation of the Railyards Specific Plan.

Table 7-3. Cumulative Traffic Noise Levels with and without Project

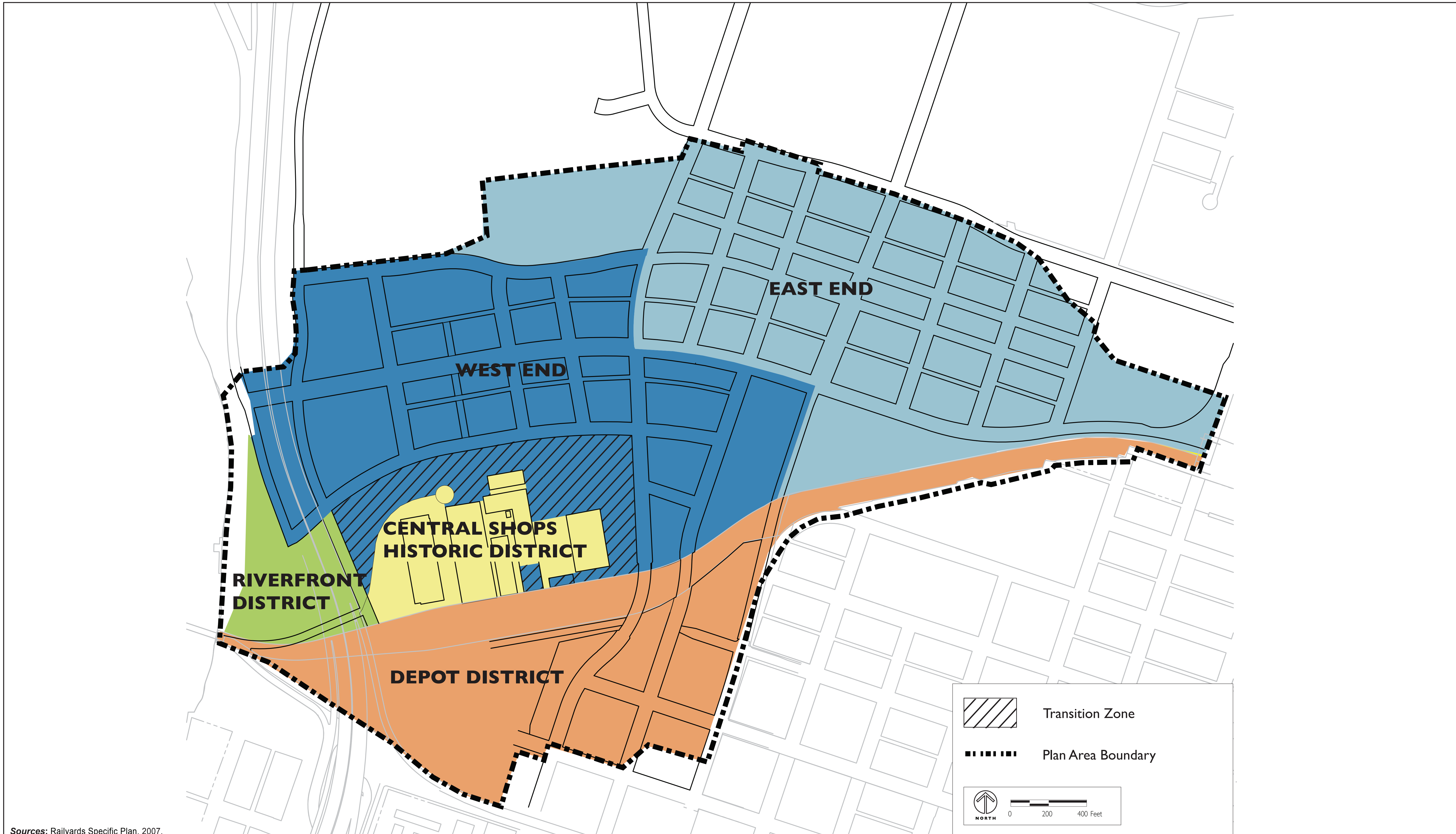
Receptor Location	Roadway	Noise Levels (CNEL)				
		Existing No Project (dB)	Cumulative without Project (dB)	Cumulative with Project (dB)	Change over Existing (dB)	Project Contribution (dB)
517 7th Street	7th Street, south of E Street	66.6	71.5	67.8	1.2	-3.7
619 12th Street	12th Street between F and G Streets	69.9	70.5	70.5	0.6	0.0
Econo Lodge (along 16th Street)	16th Street between G and H Streets	71.1	71.6	71.4	0.3	-0.2
1239 Richards Boulevard	Richards Boulevard east of Del Rios Street	66.3	71.1	69.6	3.3	-1.5
North B Street and Bannon Street	North B Street east of 7th Street (and the proposed 5th Street extension)	63.7	65.9	68.9	5.2	3.0
7th Street within the Specific Plan Area	7th Street south of North B Street	68.3	73.2	69.5	1.2	-3.7

Source: PBS&J/EIP 2007 in City of Sacramento 2007.
Notes:
1. Noise levels were calculated based on peak-hour traffic volumes proved by Dowling Associates, Inc. PM peak-hour traffic volumes were used for all roadway segments except 12th Street, where the AM peak hour represented the worst-case noise level increase.
2. Cumulative is analyzed for be Year 2030. Cumulative Plus Project assumes Full Buildout of the project by the year 2030.

Because the anticipated increases in noise are predicted to be 3 dB or less (barely perceptible) the project-related increase in noise is not considered to be adverse.

7.2. Future Vibration Environment, Impacts, and Mitigation

Groundborne vibration effects from rail and highway operations in the project area and the effect of the track relocation have been evaluated in detail in WIA 2007. Table 7-4 summarizes the results of the analysis. Figure 7-2 shows the districts where the assessment points are located. (The Museum of Railroad Technology would be located in the Central Shops District and the Performing Arts Facility would be located in West End District).



Sources: Railyards Specific Plan, 2007.

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Figure 7-2
District Boundaries

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Table 7-4. Projected Groundborne Vibration and Noise at the Location of the Closest Sensitive Receptors

Rec. ID	Rec. Dist. Location	Source	Land Use	Side of Track	Speed (mph)	Distance to Near Track CL (feet)	Track Type	FTA GBV Criteria, VdB	Projected GBV, VdB (re 1 µin/sec)	Type of Impact	FTA GNB Criteria, dBA	Projected GBN, dBA (re 20 µPa)	Type of Impact
1	Museum of Railroad Technology	Freight	INST	N	30	45	AG	75	91	I	40	51	I
		Pass			10	70			80	I		47	I
2	Performing Arts Facility	Freight	PA	N	30	520	AG	65	77	I	25	27	I
		Pass			10	550			63	NI		30	I
3	Parcel 47b – West End District	Freight	MFR	N	30	45	AG	72	91	I	35	51	I
		Pass			10	45			84	I		51	I
		LRT		E	35	150	EM		74	I		27	NI
4	Parcel 51 – East End District	Freight	MFR	N	30	100	AG	72	88	I	35	44	I
		Pass			30	100			84	I		51	I
5	Parcel 44 – Depot District	Freight	MFR	S	30	250	AG	72	83	I	35	34	NI
		Pass			10	90			78	I		45	I
		LRT			20	20	EM		74	I		50	I
6	Parcel 12 – West End Dist.	I-5	MFR	E	–	80	–	72	70	NI	35	20	NI

Source: WIA 2007.

Pass = passenger trains, Amtrak or high-speed trains (California high-speed rail).
LRT = light-rail train.
I-5 = vehicle traffic in Interstate 5.
MFR = multifamily residence.
PA = performing arts.
INST = institutional.
AG = at-grade ballast and tie track.
EM = at-grade embedded track.
I = impact as defined by FTA.
NI = no impact as defined by FTA.

It is important to recognize that the track would be relocated before most of these uses would be developed. Accordingly, the impacts identified in Table 7-4 would not occur until the development is implemented. However, there are existing uses in the Depot District where FTA criteria are predicted to be exceeded. In addition, the historic buildings in the Central Shops District may be considered fragile historic buildings. For the purposes of this analysis these buildings are considered to fall into the category of "buildings extremely susceptible to vibration damage" as indicated in Table 4-6. The corresponding impact threshold for these types of buildings is 90 VdB (Table 4-6). The results in Table 7-4 indicate that buildings in the Central Shops District could be exposed to ground vibration as high as 91 VdB. Accordingly, vibration from the track relocation is considered to result in an adverse effect on those buildings because of the potential for damage.

WIA 2007 provides a detailed discussion of options for mitigating vibration from the track relocation. The report states that the available mitigation measures are essentially limited to a maximum vibration reduction of 15 VdB. With vibration levels as high as 16 VdB above the FTA criterion in the Central Shops District, the report acknowledges that it might not be feasible to reduce vibration to the occupied use criterion level of 75 VdB for the current building siting plan. It does appear feasible that vibration can be mitigated to reduce vibration below the 90 VdB damage threshold.

The following is a summary of mitigation options for reducing vibration from the track relocation presented in WIA 2007.

- **Increase distance to buildings:** Locating vibration sensitive receptors further away from the rail alignment could help reduce the level of impact. The following distances are based on projected groundborne vibration levels in the ground. A thorough review of the proposed structural properties of the buildings when they are available could alter the screening distances. All distances are measured from the closest track centerline. At this stage of the analysis, the minimum recommended distance for residential buildings is 700 feet from freight trains traveling at 30 mph, 200 feet from passenger trains traveling 10 mph (west of Seventh Street), and 450 feet for passenger trains traveling 30 mph (east of Seventh Street).

- **Soil densification:** the increase of the soil stiffness under the track will theoretically reduce the force that the rail vehicle is capable of imparting to the soil and if so then the resulting soil vibration levels should be lower. However, this type of mitigation does not appear capable at this point of providing enough reduction by itself to achieve levels specified by the FTA criteria. Moreover, the extent of this type of solution should go down to the naturally occurring stiffer layers of soil, which may require treatment that is very deep. It is anticipated that treatment of the soil to depths of at least 30 feet or deeper would provide benefits on the order of about 4 VdB of reduction. Detailed investigation and analysis of the local soil characteristics should be performed prior to further analyzing this mitigation approach.

- **Trenches:** The use of trenches could mitigate vibration from the UPRR rail. This method is more effective when trenches are located next to the rail alignment. Trenches work in a manner analogous to a sound wall. However, a general rule of thumb as presented by FTA is that the bottom of the trench should be at least 0.6 times the Rayleigh wavelength. Based on the initial third-octave band analysis, vibration mitigation must be achieved for frequencies of 6 Hz and higher. The equivalent trench depth for standard soil at a frequency of 6 Hz would be approximately 60 feet. The expected reduction in vibration levels could be on the order of 4 to 5 VdB with this method.

- **Piles under track bed:** Another mitigation alternative is to construct a concrete track bed over deep and massive piles. Piles would need to be driven about 60 feet deep into the soil. The expected vibration reduction provided by this type of mitigation is no more than 5 VdB under optimal circumstances.

- **Tire-derived aggregate (TDA):** The use of shredded scrap tires as a vibration isolating medium for rail is relatively recent. TDA as a vibration reduction medium consists of the construction of a compacted layer of shredded tires approximately 12 to 18 inches thick located below the sub-ballast and ballast layers of track. This system has been installed at selected locations on two transit systems, the Santa Clara Valley Transportation Authority’s Vasona Line and at Denver's TREX light rail line. Recent investigation indicates that the performance is more effective than a ballast mat, but less effective, particularly at lower frequencies, when compared to the performance of a floating slab track bed system.

- **Floating slab tracks:** This approach basically consists of a massive concrete slab supported on elastomeric elements, normally natural rubber. Several designs have been successfully used for heavy rail transit systems, such as in Washington DC, Atlanta, Boston, and the Bay Area on the San Francisco Bay Area Rapid Transit District (BART) system. This specific design consists of concrete slabs that are normally 6-feet long and supported vertically on four natural rubber pads per slab.

Each slab is held in place in the lateral direction by natural rubber “side pads” that bear against a curb constructed in a concrete bathtub (shallow retained cut). In the longitudinal direction, natural rubber pads separate adjacent slabs. All of the horizontal (lateral and longitudinal) restraint pads are pre-compressed during installation. One of the most significant design parameters of the floating slab track bed is the fundamental natural frequency of the track bed in the vertical direction. The appropriate floating slab natural frequency depends on the groundborne vibration frequencies, which require reduction. To date, floating slab track bed designs have been in the 8 to 16 Hz range. The design for the BART system was targeted to achieve an 8 Hz natural frequency, because of unusual circumstances primarily involving soil conditions.

Chapter 8. Construction Noise and Vibration

8.1. Construction Noise

During track relocation and construction of projects identified under each phase of the project, noise levels would be produced by the operation of heavy-duty equipment and various other construction activities. Similar to other projects in the area, pile driving could be used for building and track bed foundations. 8-hour L_{eq} construction noise levels have been estimated using FTA methodology for various typical construction phases. The noise levels associated with equipment to be used during the various project construction phases are shown in Table 8-1.

There are sensitive uses surrounding the project area—specifically, residential uses to the north, south, and southeast. Construction noise would affect surrounding uses to varying degrees throughout the period of construction including site grading, excavation for infrastructure and building foundations, pile driving, building construction, and paving and landscaping installation. Sacramento Municipal Code, Title 8 (Health and Safety), Chapter 8.68 (Noise Control) limits construction activity to the period between the hours of 7 a.m. and 6 p.m., Monday through Saturday. Construction is also limited to the hours between 9 a.m. and 6 p.m. on Sunday. Because typical sleeping hours fall outside the time during which construction must occur, construction noise would not be expected to disturb the sleep of nearby residents.

Office and commercial uses in the vicinity of the Specific Plan Area would be open during the day when construction would occur. The noise from construction could disturb people working in these buildings. Older California building standards (pre-1970) generally provide a reduction of exterior-to-interior noise levels up to about 20 dB with closed windows; newer buildings generally provide a reduction up to about 30 dB. Accordingly, interior noise levels would be 20–30 dB less than the levels shown in Table 8-1.

Pile driving noise typically can be as high as 101 dBA at 50 feet from the hammer (FTA 2006) and may be audible within buildings in and near the project area. While it is anticipated that most occupants of the closest residential units would be at work during the day, occupants of commercial offices would be at work during the day and could be affected by pile driving activities.

Table 8-1. Estimated Construction Noise Levels (dBA)

Construction Equipment	8-hour L_{eq}		
	25 feet	50 feet	75 feet
Demolition			
Track hoe	96	90	87
Crane	94	88	85
Excavator / loader	91	85	82
Water truck	94	88	85
Site work			
Crawler tractor	91	85	82
Grader	91	85	82
Loader	91	85	82
Compactor	88	82	79
Water truck	94	88	85
Pile driver	107	101	98
Foundation			
Backhoe	86	80	77
Loader	91	85	82
Forklift	85	79	76
Water truck	94	88	85
Utilities			
Back hoe	86	80	77
Water truck	94	88	85
Forklift	85	79	76
Slab on Grade			
Skip loader	88	82	79
Bobcat tractor	90	84	81
Forklift	85	79	76
Steel erection			
Crane	94	88	85
Air compressor	87	81	76
Generator	87	81	78
Forklift	85	79	78
Decking/slabs			
Generator	87	81	78
Forklift	85	79	76
Concrete pump	88	82	79
Completion			
Forklift	85	79	76

Source: PBS&J/EIP 2007 in City of Sacramento 2007.
Notes: Noise levels calculated from equations defined by FTA 2006, pages 12-2 to 12-7.

FTA guidance indicates that 8-hour L_{eq} construction noise levels should not exceed 80 dBA during the day and 70 dBA at night at residences. The guidance also indicates that 8-hour L_{eq} construction noise levels should not exceed 85 dBA at commercial uses as any time. The results in Table 8-1 indicate that construction noise could exceed these levels at nearby residential and commercial uses. Accordingly, construction noise is predicted to result in an adverse noise impact.

Implementation of the following mitigation measures would reduce exposure of occupants on- and off-site to the maximum extent feasible; however, due to the potential use of pile driving and other noisy construction activities, it may not be feasible to reduce noise below the FTA guideline levels in all cases.

Whenever construction occurs adjacent to occupied residences (on- or off-site), temporary barriers can be constructed around the construction sites to shield the ground floor of the noise-sensitive uses. Construction activities should be conducted to comply with the City's Noise Ordinance, which limits such activity to the hours of 7 a.m. to 6 p.m., Monday through Saturday, and 9 a.m. to 6 p.m. on Sunday, prohibits nighttime construction, and requires the use of exhaust and intake silencers for construction equipment engines. Construction equipment staging areas should be located as far as feasible from residential areas while still serving the needs of construction contractors. Quieter "sonic" pile-drivers can be used, unless engineering studies indicate that it is not feasible or cost-effective, based on geotechnical considerations.

8.2. Construction Vibration

Certain construction activities could result in high levels of groundborne vibration. Table 8-1 summarizes vibration levels produced by equipment that is likely to be used in the project area.

Table 8-2. Vibration Source Levels for Construction Equipment

Construction Equipment	PPV at 25 feet (in/sec)	Approximate VdB at 25 feet
Pile Driver (impact)		
Upper range	1.518	112
Typical	0.644	104
Pile Driver (sonic)		
Upper range	0.734	105
Typical	0.170	93
Vibratory roller	0.210	94
Hoe ram	0.089	87
Large bulldozer	0.089	87
Caisson drilling	0.089	87
Loaded trucks	0.076	86
Jackhammer	0.035	79
Small bulldozer	0.003	58

Source: FTA 2006 in City of Sacramento 2007.

These values are compared to FTA vibration damage criteria previous presented in Table 4-6. This comparison indicates that pile driving and other high-impact equipment could expose existing buildings in the project area to vibration that has the potential to cause damage. The historic buildings in the Central Shops District in particular may be susceptible to damage from pile driving and other impact activities. This is considered an adverse effect.

Measures that can be used to limit vibration from construction equipment include using drilled piles or using a sonic or vibratory pile driving instead of high-impact pile drivers. Alternative demolition methods that do not involve impact can also be used. For example, sawing concrete decks into sections that can be loaded onto trucks can result in lower vibration levels than impact demolition by pavement breakers.

Chapter 9. References

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