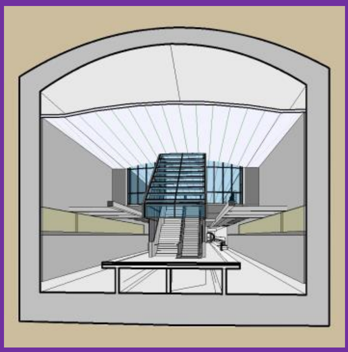
LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

WESTSIDE PURPLE LINE EXTENSION PROJECT, SECTION 2 ADVANCED PRELIMINARY ENGINEERING

Contract No. PS-4350-2000



Beverly Hills High School Master Plan Groundborne Vibration Assessment – Revision 1

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PREFACE

The Beverly Hills High School Mater Plan Ground borne Vibration Assessment was shared with the City of Beverly Hills and the Beverly Hills Unified School District in February 2017 as part of the Section 4(f) consultation process for the publicly used recreational facilities at Beverly Hills High School. This revised version of the memo addresses comments and concerns received in letters from the City of Beverly Hills on April 4, 2017 and BHUSD on April 7, 2017.

1.0 INTRODUCTION

This memorandum presents groundborne vibration and noise predictions for the Beverly Hills High School (BHHS) Master Plan related to operations of Section 2 of the Westside Purple Line Extension (the Project). Detailed methodology and previous predictions for tunneling operations for the Project are presented in the *Westside Subway Extension Final Environmental Impact Statement/Environmental Impact Report (EIS/EIR)* (Metro 2012) and the *Westside Subway Extension Noise and Vibration Study* (Metro 2011).

Since the publication of the Final EIS/EIR, the Beverly Hills Unified School District (BHUSD) has developed a proposed modernization plan for the BHHS campus, which is located above the Section 2 tunnel. In 2008, BHUSD issued the *Draft Facilities Master Plan* that was accepted by the California Board of Education and became final in 2010. The *Beverly Hills High School, Hawthorne K-8 School, and El Rodeo K-8 School Improvement Project EIR* was completed in 2015. As shown in Figure 1-1, the BHHS modernization program as it was analyzed in the BHUSD Master Plan 2015 EIR includes:

- Improvements/modifications to Buildings A (Main Class Rooms), B1 (Domestic Science), B2 (Old Class Rooms), Building B3 (Peters Auditorium), Building B4 (Salter Wing), Building F (Swim Gym), and Building L (Science Laboratories)
- Construction of a new athletics building with subterranean parking (Building C)
- Construction of an aquatics center
- Demolishment of Buildings E (Gymnasium) and Building H (Maintenance & Operations; Moreno High School)
- Reconfiguration of athletic fields
- New pedestrian plaza, enhancements to "graduation lawn", and conversion of Heath Ave into a pedestrian Walk
- Existing parking garage in Building A used by students and staff will remain, but circulation down Heath Avenue will be eliminated.

In total, the modernization will increase BHHS campus parking from 544 spaces to 712 spaces. During construction, portable classrooms will temporarily be located on the current lacrosse fields, which are immediately to the east of and adjacent to the Century City Constellation Station construction staging areas. Construction within the campus began in 2015 and is expected to be completed by 2020, with some construction activities overlapping with the Century City Constellation Station construction activities.

The only planned facility in the BHHS Master Plan that is located directly over the Section 2 tunnel is the proposed Building C Athletics (Figure 1-1). According to the Master Plan, the most sensitive uses within this proposed building will be the Gymnasium (recreational facility under Section 4(f)) and Physical Education (PE) office on the second floor of this building. The other occupied spaces in this building, locker rooms, showers, and rehab spaces are not considered by Federal Transit Administration (FTA) Transit Noise and Vibration Impact Assessment Report (FTA, 2006) as noise or vibration sensitive uses. A subterranean parking structure is also proposed to be located beneath Building C. This memorandum analyzes the groundborne vibration and noise predictions at Building C Gymnasium and PE Office during the operations of Section 2 of the Project both with and without the completion of the proposed subterranean parking structure. The proposed plans and cross section of Building C, including the parking structure, is in Appendix A.

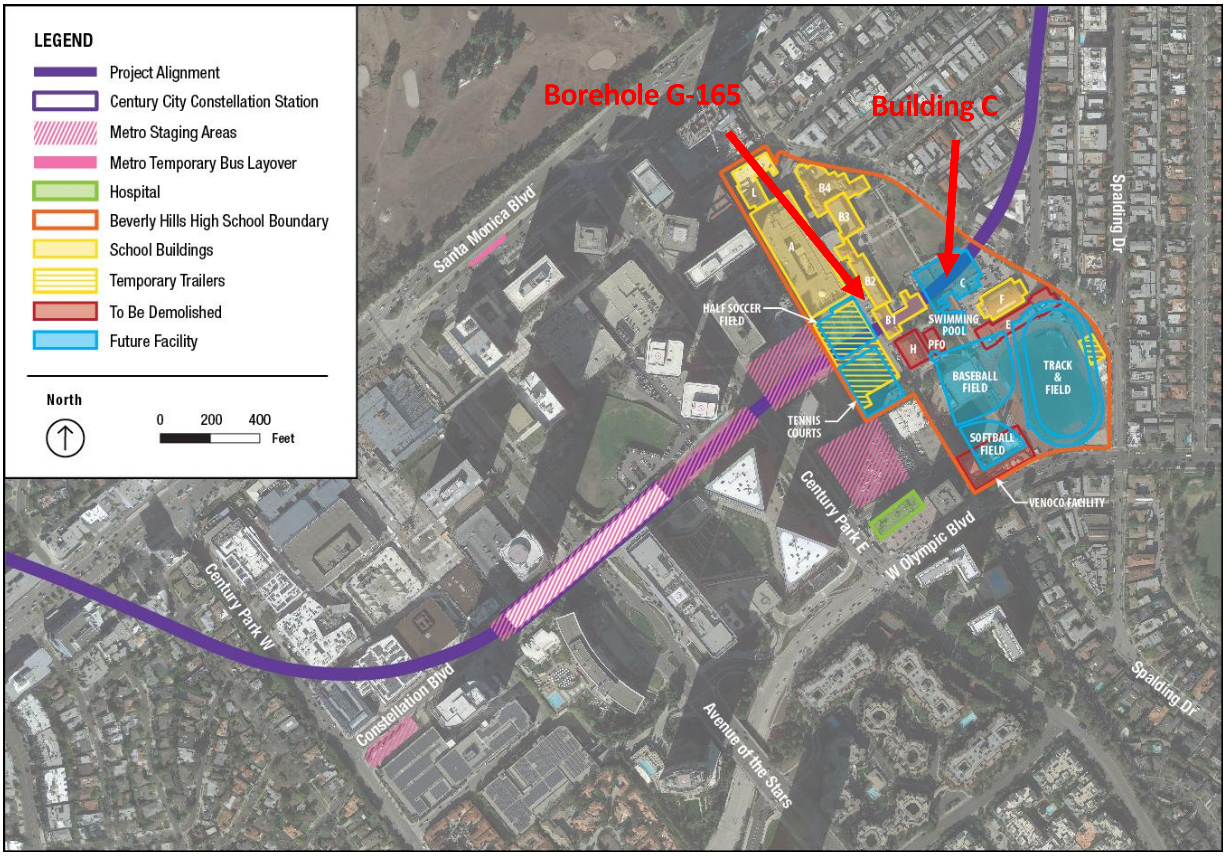


Figure 1-1: Century City Station and Beverly Hills High School

2.0 METHODOLOGY

Vibration impacts from transit operations are generated by motions/actions at the wheel/rail interface. The smoothness of these motions/actions is influenced by wheel and rail roughness, transit vehicle suspension, train speed, track construction (including types of fixation), the location of switches and crossovers, and the geologic strata (layers of rock and soil) underlying the track. Vibration from a passing train has a relatively small potential to move through the geologic strata and result in building vibration from energy transferred through the building's foundation. Vibration levels that would be high enough to cause any building damage, even minor cosmetic damage, are extremely unlikely. Groundborne noise is a low-frequency rumble related to operational vibration that may occur when excessive levels of vibration of a building's floors and walls result from transit system operations. Groundborne noise is not generally a concern for at-grade or above ground transit operations because the level of airborne noise from a passing at-grade or elevated train that is transmitted through the windows or walls of a building would exceed the groundborne noise level occurring inside the building. However, a deep subway produces no appreciable airborne noise above the ground surface; therefore, the analysis considers the groundborne noise related to the operational vibration, since the groundborne noise may be slightly audible within a building that otherwise has low internal background noise. Because groundborne noise is directly related to groundborne vibration, the level of groundborne noise is a function of the distance from the tracks to the building.

Groundborne noise is considered for the potential to create an annoyance as well as the potential to damage buildings:

- **Human Annoyance from Vibration:** Potential human annoyance from vibration is assessed using root mean squared (RMS) vibration velocity. Groundborne vibration from transit vehicles is characterized using RMS vibration velocity amplitude expressed as VdB. The vibration perception threshold for most humans is around an RMS vibration level of 65 to 70 VdB. Levels from 70 to 75 VdB are typically noticeable but acceptable to most persons. Levels higher than 80 VdB are often considered unacceptable.

- **Building Damage from Vibration:** Vibration, as it is related to risk of building damage, is generally assessed in terms of peak particle velocity (PPV) in units of inches per second (in/sec). The damage risk threshold from construction vibration ranges from 0.12 in/sec for historic buildings and cultural resources to 0.5 in/sec for architectural damage to 2.0 in/sec for structural damage. These levels are significantly greater than the FTA vibration criteria of 72 to 75 VdB for train operations.

Following FTA guidance established in the *Transit Noise and Vibration Impact Assessment* (FTA 2006), the significance of vibration impacts is based on the vibration level, the type of land use, and whether the vibration events occur frequently, occasionally, or infrequently. Frequent events are more than 70 vibration events of the same source per day. Most transit subway projects, including this one, fall into that category.

Excessive ground vibration from transit subway operations can sometimes result in a low-pitched rumbling sound occurring within a nearby building during the train pass-by called groundborne noise. The FTA groundborne vibration and groundborne noise impact criteria are shown in Table 2-1.

The groundborne noise and vibration analysis uses vibration impact thresholds defined by the FTA in the *Transit Noise and Vibration Impact Assessment* (FTA 2006). Schools are considered FTA Category 3 receivers in this FTA guidance. The thresholds for Category 3 receivers are 75 VdB for groundborne vibration and 40 A-weighted decibels (dBA) for groundborne noise.

Table 2-1. FTA Groundborne Vibration and Groundborne Noise Impacts Criteria for General Assessment

Land Use Category	Groundborne Vibration Levels (VdB re 1 micro-inch/second)			Groundborne Noise Impact Levels (dB re 20 micro Pascals)		
	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]
Category 1: Buildings where vibration would interfere with interior operations	65 VdB[4]	65 VdB[4]	65 VdB[4]	N/A[5]	N/A[5]	N/A[5]
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: Transit Noise and Vibration Impact Assessment (FTA 2006)
[1] Frequent Events are defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
[2]Occasional Events are defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.
[3]Infrequent Events are defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
[4]This criterion limit is based on levels that are acceptable for most moderately sensitive equipment, such as optical microscopes. Vibration-sensitive manufacturer 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.
[5]Vibration-sensitive equipment is generally not sensitive to groundborne noise.

2.1 Transit Vibration Assessment Methodology

An important factor in projecting levels of groundborne vibration is the rate at which the vibration dissipates as it travels away from the source where it is generated. The relationship between a vibration source and the resulting vibration of the ground is known as the transfer mobility. The transfer mobility was determined by conducting vibration measurements in which the vibration pulses from a dropped weight were measured at various distances from the source. A load cell (force transducer) is used to measure the force input to the ground from the dropped weight, and calibrated vibration accelerometers are used to measure the vibration pulses at various distances from the source, as shown in Figure 2-1. The frequency-dependent propagation characteristics are derived from the transfer function relationships of the ground surface vibration and the force. The tests were conducted by dropping the weight down a borehole to the depth of the top of rail, which is the location of the vibration source that results from the train running along the rail. Downhole vibration propagation measurements were made at several places on or near the BHHS campus in 2011 in support of the Final EIS/EIR. These measurements are summarized in the Noise and Vibration Study (Metro 2011). The results of these measurements are used to make groundborne noise predictions inside the BHHS classrooms and at other receivers.

Vibration propagation tests conducted at borehole site G-165 located on Heath Avenue, directly west of Building B1 were used to assess the groundborne vibration effects on Building C. Vibration testing was conducted at three depths of 55 feet, 65 feet, and 75 feet. Several receiver positions were measured at the surface, including three measurements made inside the existing classrooms. The proximity of borehole site G-165 to the proposed location of Building C is a reasonable characterization of the ground vibration attenuation between the subway tunnel and the building foundation. The results of this testing are included in Westside Subway Extension Noise and Vibration Study (Metro 2011). The location of borehole G-165 is shown in Figure 2-2. The subway track alignment profile at the proposed location of Building C is shown in Figure 2-3

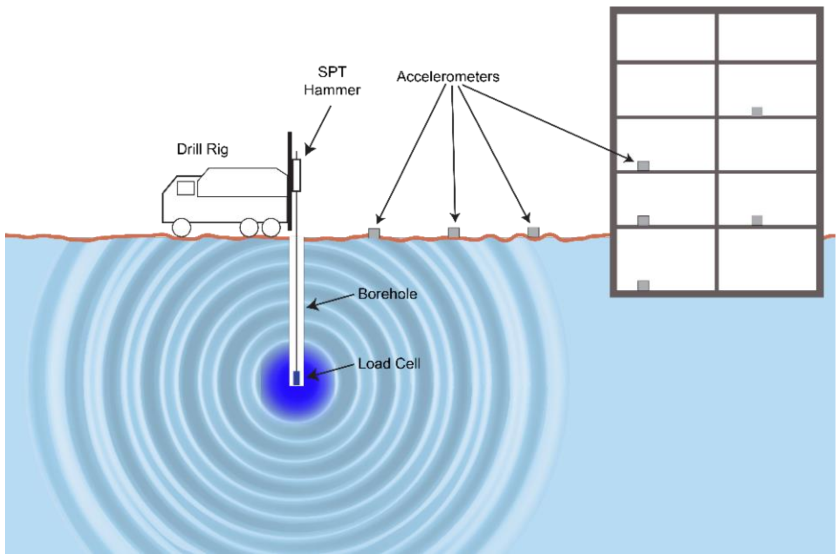


Figure 2-1: Borehole Test Configuration

The vibration propagation measurements were used to define the Line Source Transfer Mobility (LSTM) as a function of the diagonal distance from the top of rail. The LSTM is combined with the Force Density Level of a Metro Red Line Breda Vehicle, which is the predicted vibration excitation caused by the transit rail vehicle wheels as they travel along the tracks, to make groundborne vibration and groundborne noise predictions. Because a subterranean parking garage is proposed beneath Building C, the analysis assumed the recommended FTA coupling loss to building foundation for a large masonry building on spread footings.

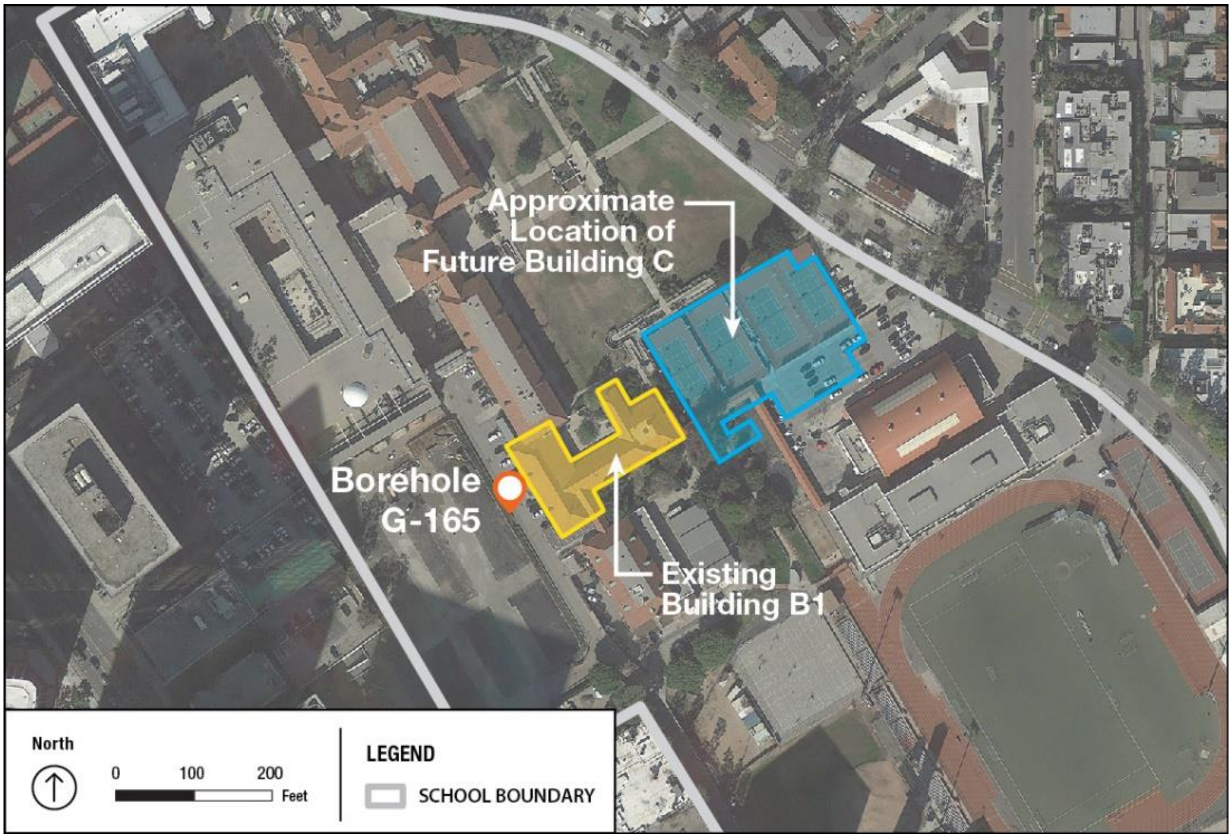


Figure 2-2: Location of Borehole and Beverly Hills High School Buildings

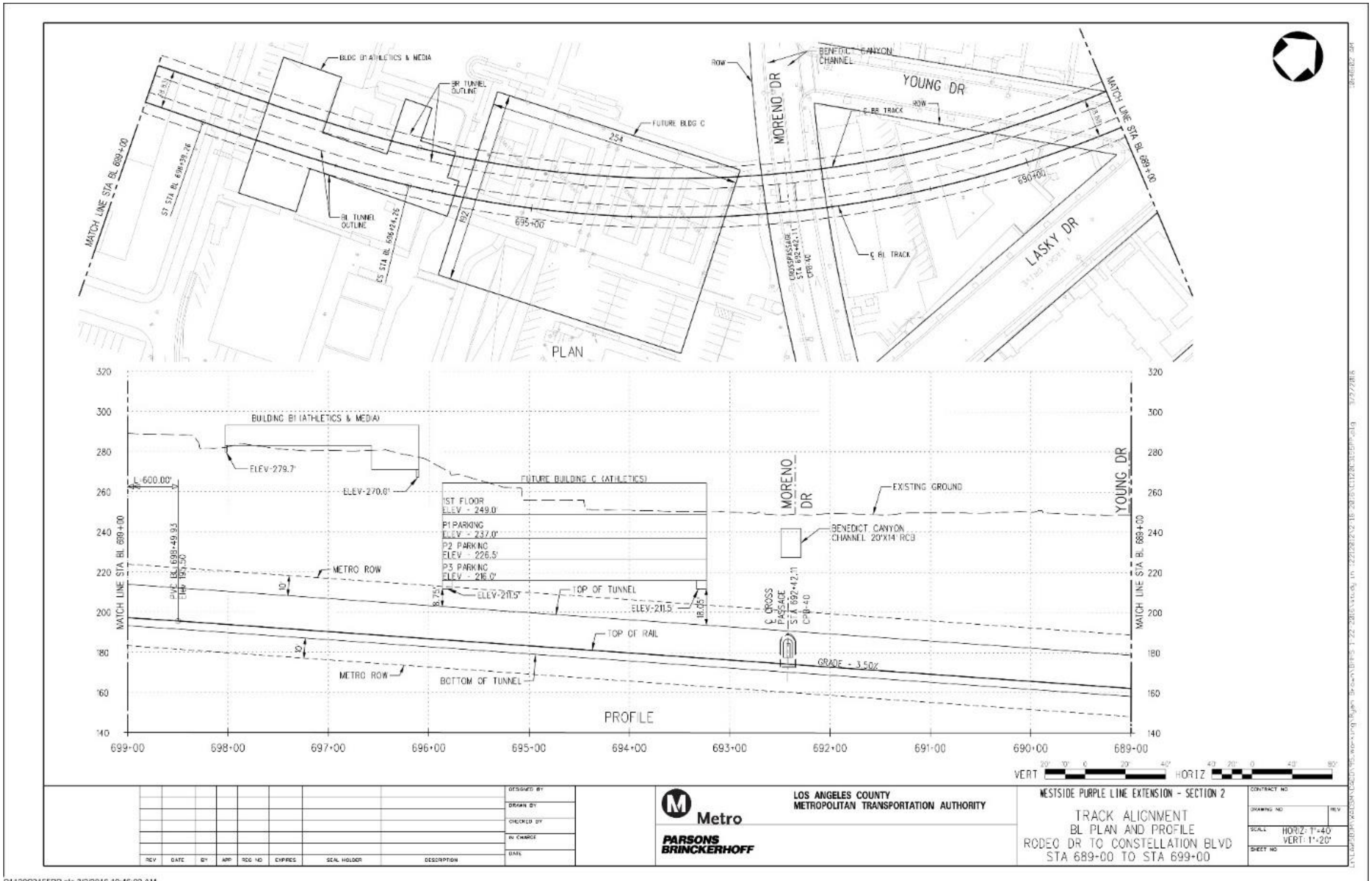


Figure 2-3: Track Alignment Profile at Building C

2.2 Groundborne Vibration Model

The predictions of groundborne vibration for this study follow the Detailed Vibration Assessment procedure of the FTA guidance manual. This is an empirical method based on testing of the vibration propagation characteristics of the soil in the project corridor and measurements of the vibration characteristics of similar light rail vehicle. The vibration propagation test is used to determine the line source transfer mobility (LSTM). The vibration characteristics of the light-rail vehicles are quantified by the force density level (FDL). The basic relationship used for the vibration predictions is:

$$Lv = LSTM + FDL + SF + Building\ Adj.$$

Lv	=	Predicted vibration level inside the space
LSTM	=	Measured line surface transfer mobility
FDL	=	Force density level
SF	=	Safety factor to account for uncertainties
Building Adj.	=	Adjustment to account for attenuation or amplification as vibration travels from the soil into the building structure

The force density level (FDL) characterizes the vibration forces generated by the train and track structure. FDL measurements conducted of the Breda vehicles operating on the existing Metro Red Line, are shown in Figure 2-4.

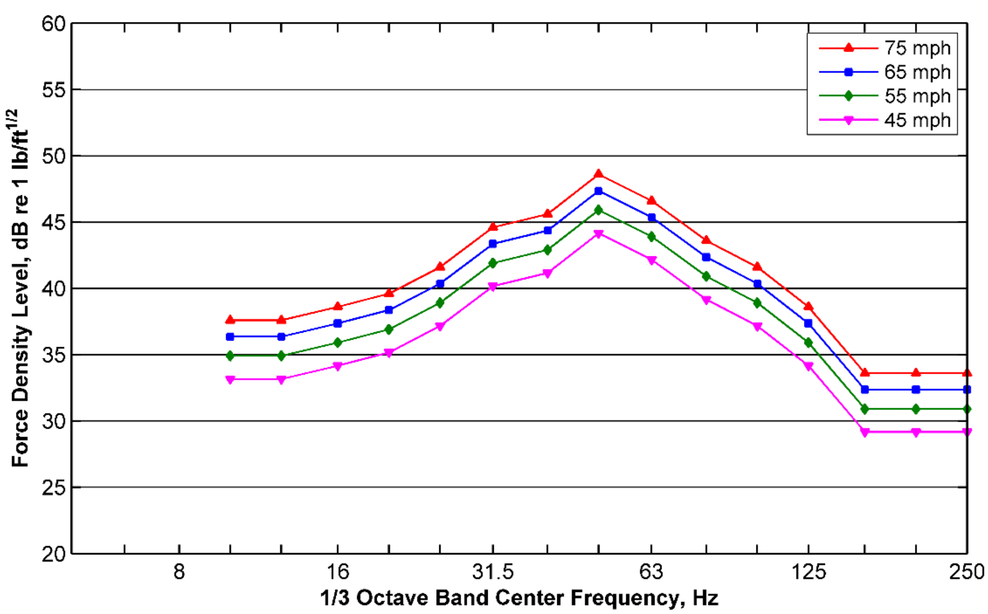
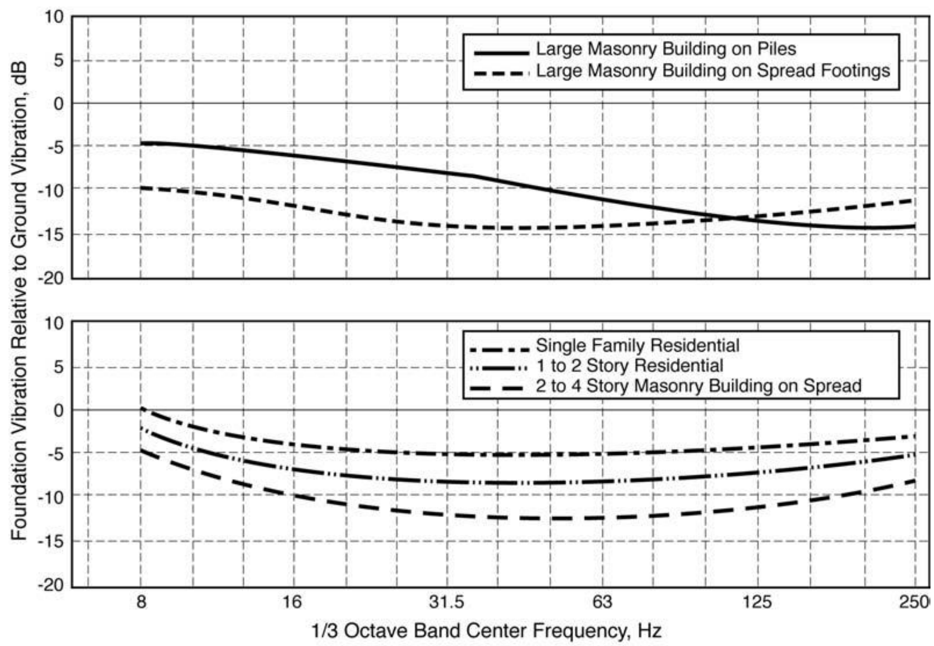


Figure 2-4: Force Density Level for Breda Vehicles

2.2.1 Building Adjustment

The propagation of vibration from the soil into the building foundation and through the building structure is complex and dependent on the specific design and construction of the building. The FTA guidance manual provides generic adjustments to account for building response and floor resonance; however, the FTA guidance manual also recommends that measured values be used in place of the generic adjustments when available. Because this analysis is for a proposed building design it is not possible to conduct building response measurements. The Building C adjustment factors includes coupling loss as the vibration travels from the soil into the building foundation, and transmission loss as the vibration travels though the building as shown in Figure 2-5.

Figure 2-5: Foundation Response for Various Types of Buildings



Source: FTA Transit Noise and Vibration Impact Assessment, May 2006.

2.2.2 Safety Factor

A safety factor of +5 dB is also added to each one-third octave band. The purpose of the safety factor is to account for measurement uncertainties and other error sources in the predictions. This is a conservative approach, ensuring that in most cases the predicted levels are higher than what would occur during regular operations.

2.3 Groundborne Noise Model

Groundborne noise is directly related to groundborne vibration inside the building. Groundborne noise is predicted using the following formula:

$$La = Lv + Krad + Kawt$$

La	=	Predicted A-weighted groundborne noise inside the space
Lv	=	Predicted vibration level inside the space
Krad	=	Radiation adjustment
Kawt	=	A-weighting adjustment at the 1/3 octave band center frequency

The radiation factor, *Krad*, is an adjustment to convert from groundborne vibration to sound pressure level.

The modeling assumptions used are:

- 24.5 feet depth from building foundation to top of rail at closest point with the subterranean parking structure
- 70 feet depth of building foundation to top of the rail without subterranean parking structure
- Subway alignment directly below Building C (0 feet horizontal distance)
- 6-car vehicle train operating at 45 mph
- Safety factor of +5 dB. This accounts for uncertainty in the building amplification, future rail corrugations, and wheel roughness that may result in higher than predicted groundborne vibration levels.
- Recommended FTA coupling loss to building foundation for a large masonry building on spread footings (Figure 2-5).
- Floor-to-floor attenuation of -2 dB for the second floor above grade.
- Single train passby is one train passing in one of the tunnels under Building C and a two train passby is when one train is in each of the two tunnels passing under Building C. The predicted ground vibration levels for a two train passby is 3 dB higher than a single train passby.

Refer to the *Westside Subway Extension Noise and Vibration Study* (Metro 2011) for a more detailed description of methodology and the FDL measured data of the Metro Red Line Breda vehicles that was used as the basis for this groundborne vibration assessment.

3.0 GROUNDBORNE VIBRATION PREDICTIONS

The groundborne noise and vibration analysis in the Final EIS/EIR uses vibration impact thresholds defined by the Federal Transit Administration (FTA) in the *Transit Noise and Vibration Impact Assessment* (FTA 2006). Schools are considered FTA Category 3 Receivers. The thresholds for Category 3 receivers are 75 VdB for groundborne vibration and 40 dBA for groundborne noise. Table 3-1 and Table 3-2 show the FTA thresholds and the predicted groundborne vibration and noise levels for a single train passby and simultaneous passby of two trains, respectively, for the Gymnasium and PE office in Building C, the planned future facility on the BHHS campus that would be located directly over the Section 2 tunnel, based on the vibration propagation measurements. The predicted levels are with and without a subterranean parking structure.

The modeling assumptions used for the groundborne vibration and groundborne noise analyses of Building C with slab on grade design and no subterranean parking structure are:

- 70 feet depth to top of rail at closest point
- Alignment directly below Building C (0 feet horizontal distance)
- 6-car vehicle train operating at 45 mph
- Safety factor of +5 dB. This accounts for uncertainty in the building amplification, future rail corrugations, and wheel roughness that may result in higher than predicted groundborne vibration levels.
- Floor-to-floor attenuation of -2 dB for the second floor above grade.
- Single train passby of one train passing in the tunnel under Building C and a two train passby when there are one train in each of the two tunnels passing in the tunnel under Building C. The predicted ground vibration levels for a two train passby is 3 dB higher than a single train passby.

Table 3-1. Predicted Groundborne Vibration and Noise Levels – Single Train Passby

	FTA Category 3 Thresholds	Building C Gymnasium (1st Floor) Predicted Levels	Building C PE Office (2nd Floor) Predicted Levels
With Building C Subterranean Parking Structure			
Groundborne Vibration (Lv)	75 VdB	72 VdB	70 VdB
Groundborne Noise (La)	40 dBA	53 dBA	51 dBA
Without Building C Subterranean Parking Structure			
Groundborne Vibration (Lv)	75 VdB	65 VdB	63 VdB
Groundborne Noise (La)	40 dBA	32 dBA	30 dBA

Source: Transit Noise and Vibration Impact Assessment (FTA 2006) and Beverly Hills High School Master Plan Groundborne Vibration Assessment –Revision 1 (Metro 2017f) (Appendix E)

Table 3-2. Predicted Groundborne Vibration and Noise Levels– Two Train Passby

	FTA Category 3 Thresholds[1]	Building C Gymnasium (1st Floor) Predicted Levels	Building C PE Office (2nd Floor) Predicted Levels
With Building C Subterranean Parking Structure			
Groundborne Vibration (Lv)	83 VdB	75 VdB	73 VdB
Groundborne Noise (La)	48 dBA	56 dBA	54 dBA
Without Building C Subterranean Parking Structure			
Groundborne Vibration (Lv)	83 VdB	68 VdB	66 VdB
Groundborne Noise (La)	48 dBA	35 dBA	33 dBA

Source: Transit Noise and Vibration Impact Assessment (FTA 2006) and Beverly Hills High School Master Plan Groundborne Vibration Assessment –Revision 1 (Metro 2017f) (Appendix E)
Notes: 1. FTA Category 3 thresholds for infrequent events of fewer than 30 per day.

As shown in Table 3-1, the predicted maximum level groundborne vibration and groundborne noise for a single train passby at the Building C Gymnasium and PE Office would exceed the FTA Category 3 groundborne noise threshold of 40 dBA if the subterranean parking structure is constructed as currently proposed. It is predicted not to exceed the groundborne vibration threshold of 75 VdB. If the subterranean parking structure is not constructed, the predicted train groundborne vibration and the groundborne noise levels are not predicted to exceed FTA Category 3 thresholds at the Building C Gymnasium and PE Office.

The predicted groundborne vibration and groundborne noise, presented in Table 3-2, is a maximum level for simultaneous passby of two trains. It is not expected that two trains will simultaneously pass under Building C for more than 21 times per day. The FTA threshold for infrequent events of fewer than 30 per day is used to assess the potential effect of this occurrence. If the subterranean parking structure is constructed as currently proposed, the two train predicted groundborne noise at the Building C Gymnasium and PE Office would exceed the FTA Category 3 groundborne noise threshold of 48 dBA. It is predicted not to exceed the groundborne vibration threshold of 83 VdB. If the subterranean parking structure is not constructed, the predicted train groundborne vibration and the groundborne noise levels are not predicted to exceed FTA Category 3 thresholds at the Building C Gymnasium and PE Office.

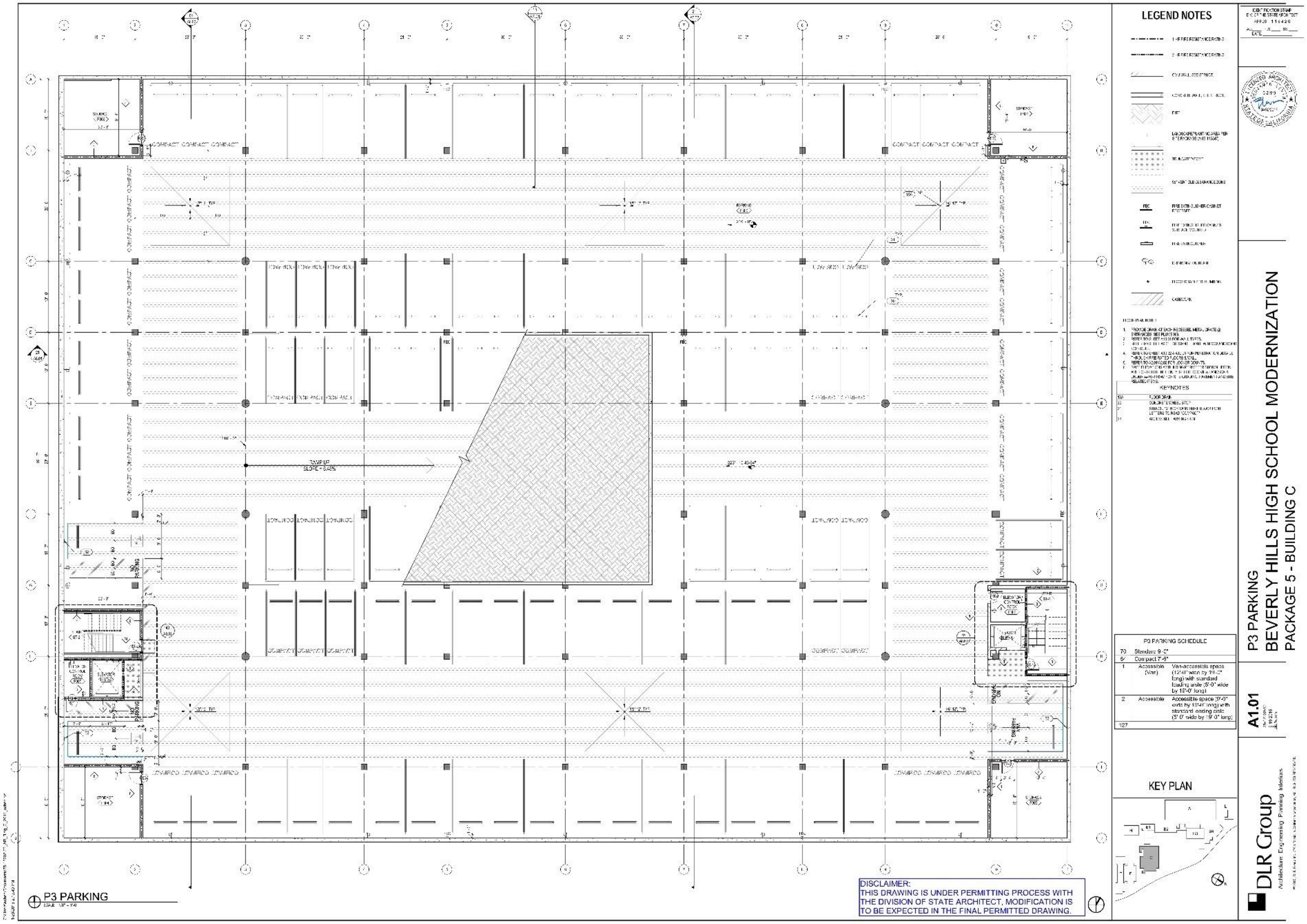
The predicted groundborne vibration and noise levels presented in Table 3-1 and Table 3-2 account for the proposed location of the Building C subterranean parking structure, which extends the building foundation to within approximately 8.5 feet of top of tunnel (24.5 feet from the top of rail). Any changes to the proposed building location and/or building design would affect the groundborne vibration and groundborne noise levels. If the distance between the top of rail and the building foundation increases, the predicted groundborne vibration and noise levels would be lower. At 40 feet or more between top of rail and building foundation, the predicted groundborne noise levels would not exceed the FTA threshold of 40 dBA at the Gymnasium or PE Office for a single train passby or 48 dBA for a two train passby.

4.0 MITIGATION MEASURES

The predicted groundborne vibration resulting from operation of Section 2 of the Project would not exceed FTA Category 3 thresholds for Gymnasium and PE office at BHHS's Building C. If the distance between the top of rail and the Building C foundation is less than 40 feet, the predicted groundborne noise levels resulting from operation of Section 2 of the Project would exceed FTA Category 3 thresholds for the Gymnasium and PE office at BHHS's Building C. With the implementation of the following mitigation, the groundborne noise level is predicted not to exceed the FTA Category 3 thresholds and no groundborne noise impacts would remain:

- Use of Groundborne Noise Minimization Techniques: If the distance between the top of rail and the BHHS Building C foundation is less than 40 feet, resilient rail fasteners, floating slab track or other similar technology will be incorporated into the project design to reduce groundborne noise to levels that do not exceed FTA Category 3 groundborne noise threshold at BHHS Building C.

APPENDIX A: BUILDING C PLANS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PACKAGE 5 - BUILDING C
A1.01
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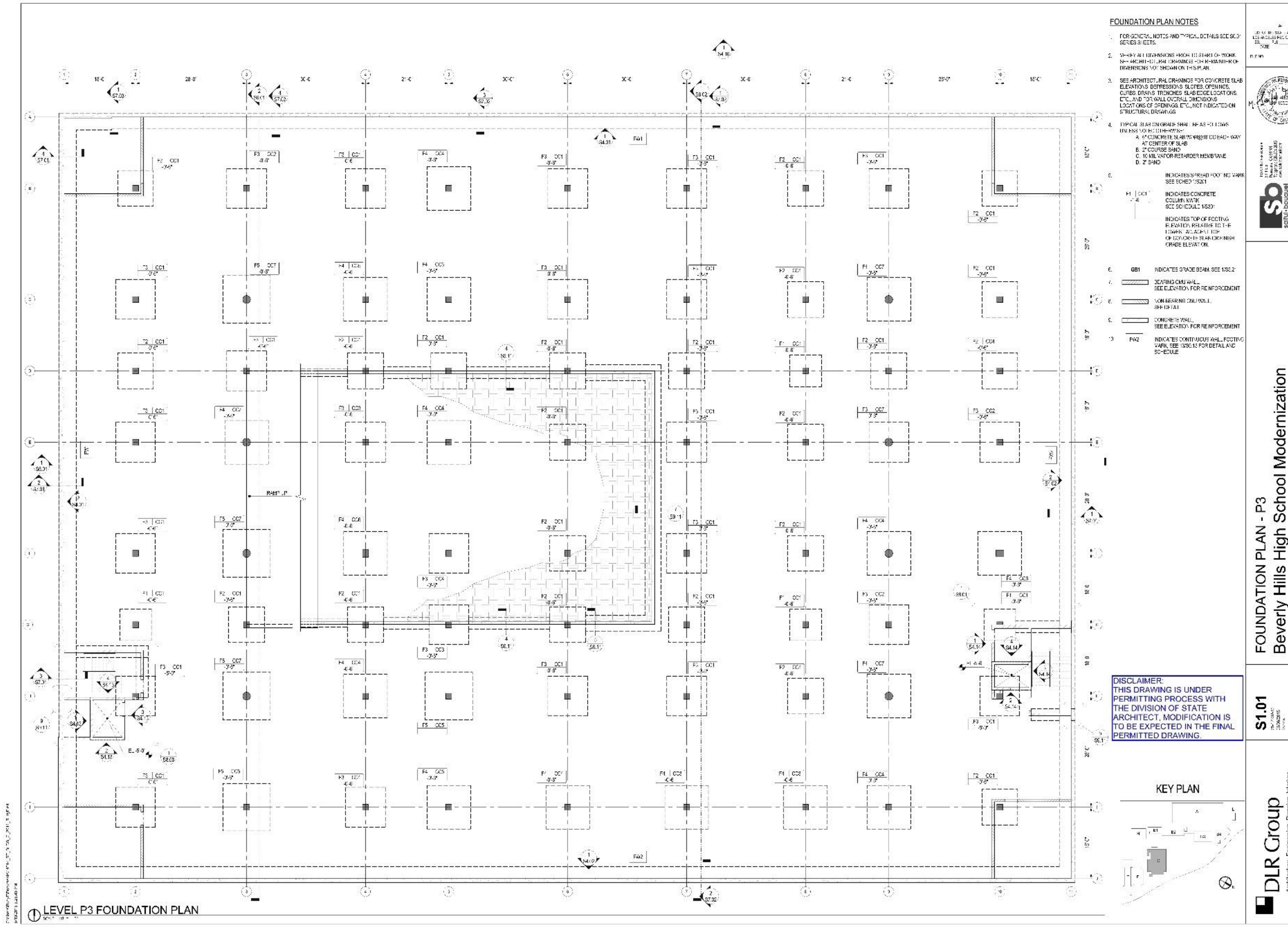
P3 PARKING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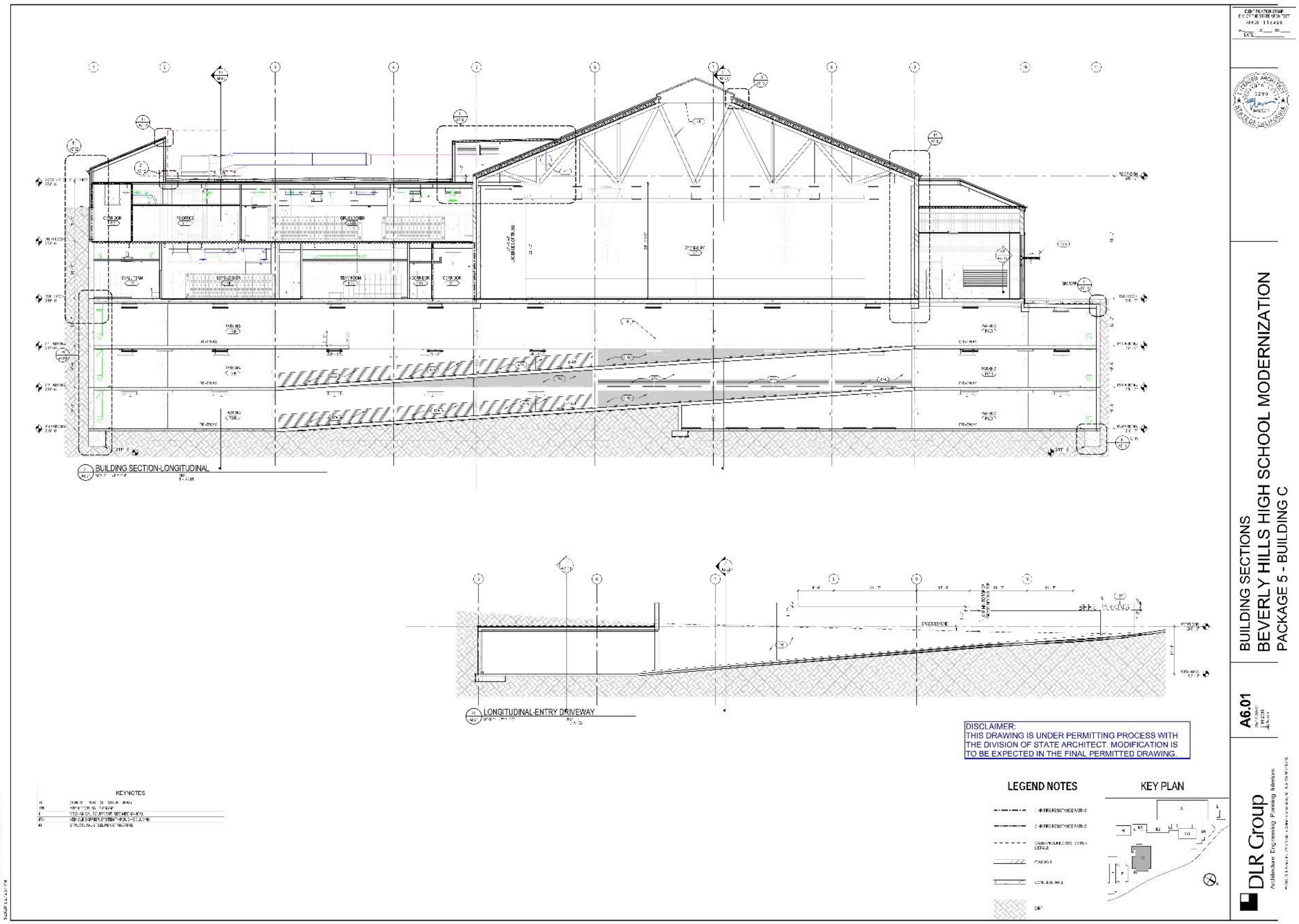
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BUILDING SECTIONS
BEVERLY HILLS HIGH SCHOOL MODERNIZATION
PACKAGE 5 - BUILDING C
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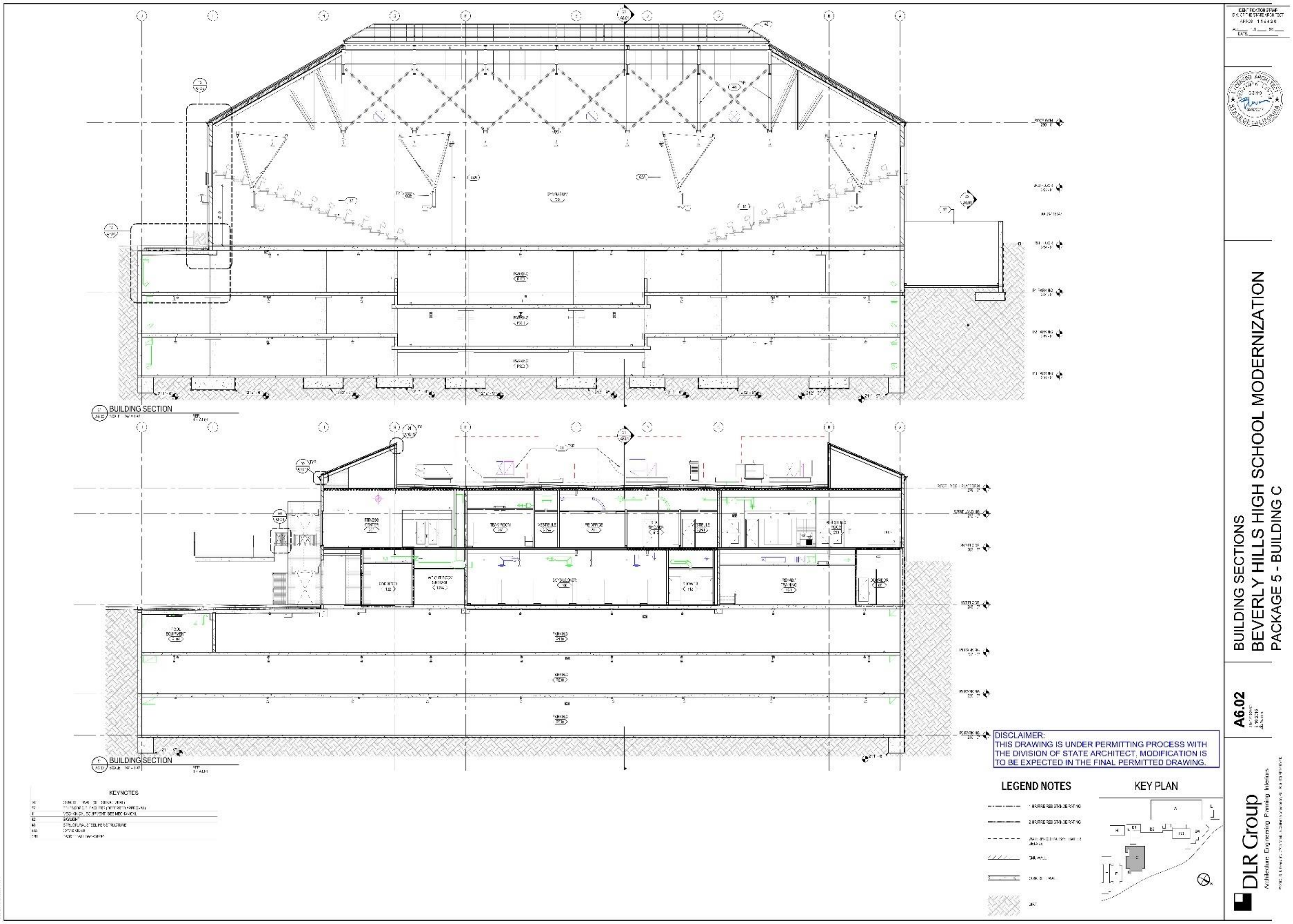
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