inter•noise 83

TRAIN NOISE IN A SHALLOW VALLEY. A CASE HISTORY.

Mauriće A. Garbell

M.A.G. Consultants, Inc. 1714 Lake Street, San Francisco, California 94121, U.S.A.

INTRODUCTION.

A dual-track railroad trunk line follows the troughline of a shallow depression in the Sierra Nevada foothills in California. "Cruising noise" and the restarting of stopped trains produce high levels of low-frequency noise at adjacent dwellings.

A residential land-use permit was sought for a one-km-long railroad-contiguous area (Fig. 1). Environmental protection agencies objected alleging "unmitigable noise impact" and requested dedication of a strip 200 meters (m) wide for public recreational purposes. A design comprising noise barriers, a resculptured topography, and structural improvements was ultimately approved. Noise measurements verified the achievement of acceptable noise levels in the project as built.

BASIC PREMISES.

Pre-existing Topography: The southern portion of the site ("S" in Fig. 1), contiguous to the tracks, was situated on an escarpment 3 m above the railbed. The remainder of the site contiguous to the tracks was 2 to 3 m below track level.

Railroad Traffic, the Principal Noise Source. 44 trains (24 "daytime," 0701-1900, 4 "evening," 1901-2200, weight factor: 3, and 16 "night-time," 2201-0700, weight factor 10), mostly heavy freight trains with 4 Diesel traction units and 80-100 freight cars, traverse the valley daily at approximately 64 kph. The daily "equivalent number of train events" is: 24 + 3*4 + 10*16 = 196.

Noise Sources on Trains.

Trains emit noise from 3 major sources: 1. Wheels and couplings, at 1 m above the tracks (ATT). 2. Engines (mechanical) at 2 m ATT. 3. Engines (exhaust) at 4 m ATT.

Typical Noise-Level-versus-Time Profiles During Train Pass-Bys.
A typical unshielded pass-by event, at a point "M" 6 m inside the property line (30 m from the track median), is depicted in Fig. 1.

Fundamental Assumptions on Existing and Acceptable Noise Levels.
Measured Background Noise Levels. 42 dBA in daytime, 30 dBA at night.
Sound Attenuation With Distance was determined by actual measurements.
Sound Attenuation by Obstacles and Barriers. A noise barrier near the tracks afforded effective protection to the proposed residential areas nearest the railbed.

Width of Noise Impact at the Site. Direct line of sight between outdoor living areas and the engine exhaust stacks was acceptable beyond 100 m, and between outdoor living areas and the sub-platform wheels, springs, couplings) beyond 120 m. However, protective measures in the design and construction of houses exposed to line-of-sight propagation of train noise were required to approximately 150 m from the tracks to afford satisfactory indoor noise levels in all habitable rooms.

Equivalent Noise Levels and Weighted Average Noise Levels. The U.S. Environmental Protection Agency (EPA) calculates the day-and-night noise exposure level "Ldn" by averaging the daytime (0701-2200) "equivalent noise level," Leq, and the "nighttime" (2201-0700) Leq augmented by 10 dB. California employs a "community noise equivalent level" (CNEL), which weights the "evening" (1901-2200) noise events additionally by a factor of 3 (4.78 dB). An exterior Ldn/CNEL of 65 dB is deemed acceptable for residential land uses. California prescribes a maximum CNEL of 45 dB in all habitable rooms. The U.S. Dept. of Housing & Urban Development (HUD) prescribes acceptable durations of specified interior Leqs.

PROTECTIVE MEASURES AGAINST NOISE FOR HUMAN DWELLINGS.

1. Outdoor Living Areas. Residential outdoor areas were to be protected against railroad-noise sources by berms and 10-cm-thick concrete-panel walls and by resculpturing of the terrain. An alternative 100-m-wide "noise-buffer zone" offered less noise protection at a higher cost.

2. Interior Habitable Areas. The sleep of future residents in the wooden frame houses was to be protected against the maximal single-event noise levels produced by train pass-bys by providing design improvements and quality controls to block "leaks" and "flanking paths" from the exterior to the interior habitable spaces.

NOISE MEASUREMENTS OF RAILROAD TRAINS.

Noise measurements were made at point "M" (see Fig. 2), 1.5 m above ground level (AGL), near the center of area of ground-floor windows in the proposed dwellings. At "M," an existing earth berm (61 m long, 1.5 m above the tracks, 2.1 m AGL) intercepts the line of sight to the subplatform portions of the trains, but not to sources of engine noise or the exhaust stacks. The single-event noise-exposure levels produced by trains (see Fig. 2), for 196 equivalent pass-by noise events, yielded an Ldn/CNEL)=68 dB for the monitoring site. A 2.5-m berm would have produced an acceptable Ldn=65 dB. However, an unshielded 90-dBA maximum outdoor engine-noise level and a maximum indoor noise level of 70 dBA, assuming an outdoor-to-indoor noise reduction of 20 dB, were regarded as excessive.

INITIAL RECOMMENDATIONS.

1. Protection for Outdoor Residential Areas.
Differing resculpturing of the topography was applied to Areas S and N.
Area S. The cross-sectional topography of Area "S" was modified as shown in Figs. 3 and 4. A barrier, cresting at 5 m above track level (2 m above local ground), was set on the right-of-way boundary. Houses adjacent to the right-of-way had blank walls facing the low-frequency engine noise and exhaust noise of the locomotives.
Area N. The terrain in Area "N" was resculptured as shown in Figs. 2 and 3. A berm+concrete barrier 2.5 m high was to be placed along the railroad right-of-way.
Redwood Fences. Gapless redwood fences were placed as shown by dotted lines in Fig. 2 to increase the "excess ground attenuation" in depth.

2. Outdoor-to-Indoor Noise Insulation.
Specific improvements were included in the dwellings on the "most exposed lots" facing the railroad tracks as follows: In Area S: All of the lots. In Area N: The lots shaded in Fig. 1. The improvements comprised: (a) Blown roof insulation. (b) All openable windows, glass doors, etc. sealed when closed. (c) Solid-core exterior wooden doors. (d) Tightly closing dampers for fireplace flues. (e) Exterior walls and ceilings free of cracks. (f) Metal pipes and conduits passing through exterior walls to be caulked. (g) Bends in all outdoor-vented ducts having an exterior vent.

INITIAL RESPONSE OF LOCAL AND FEDERAL GOVERNMENT.

Local government disagreed with the afore-described assessment and plan, stating that much "of the engine noise (mechanical and exhaust) originating from points high off the ground (2 and 3.5 m respectively) would defy mitigation by barrier and contouring schemes and would remain 'excessive' and 'objectionable'." There were also reports of unmitigable ground vibration and rattling of dishes in the kitchen cupboards of existing old houses alongside the railroad tracks.

Noise Measurements at the Site and at a Comparable Site. Noise measurements at the site showed that, without intervening shielding, the strongly horizontal "aim" of the sub-platform noise produced an exceptionally low attenuation rate versus distance throughout the amphitheater-shaped site, wherever the direct line of sight from the more distant rising terrain scanned the subplatform portions of the train cars. To determine the effectiveness of a 2.5-m barrier, field measurements at an existing barrier-protected site of comparable general shape were required. A residential tract on the opposite side of the tracks, protected by an earth berm (Fig. 5), could be used for on-site noise measurements.
Measurements were made at five noise-monitoring stations (Fig. 2) in the existing antisymmetrical tract. Locomotive engine noise (from a source 1.8 m above track level) was found to be reduced 6 dB per doubling of distance along a free-air direct line of sight, 7 dB along a direct line of sight flanked and laterally restricted by intervening houses, and 8 dB or much more across the built-up residential area.
At the station 80 m from the tracks, the following average values of the barrier effectiveness prevailed:

Microphone elevation.	Barrier intercept.	Noise reduction vs. an unshielded location. Engine sources.	Subplatform sources.
1.5 m	2.8 m	22 dBA (to 68 dBA)	12 dBA (to 64 dBA)
3.1 m	1.7 m	16 dBA (to 74 dBA)	10 dBA (to 66 dBA)
4.9 m	1.1 m	12 dBA (to 78 dBA)	4 dBA (to 72 dBA)

This high barrier effectiveness was attributed to the predominantly horizontal "aim" of the mechanical engine noise and the slope and damping of the berm intervening between the rail line and noise-monitoring station. It was concluded that the recommended barrier on the project site would limit the noise-level maxima at a 1.5-m elevation 15 m inside the property to less than 75 dBA.
Investigation showed that the reports on "ground vibration" had been based on observations of "droning" of ground-level flooring in houses built on perimeter foundations (not concrete-slab foundations), in which the crawlspace cavity within the perimeter foundation reverberated in response to airborne low-frequency noise.

OPINION SURVEY.

An opinion survey and verifying noise measurements by local government confirmed the findings described herein. The project was approved by the authorities.

SUBSEQUENT NOISE MONITORING.

Upon completion of the first rows of houses, noise monitoring was performed in the interior of the most directly exposed second-story bedroom, located at the eastwardly oriented corner of a dwelling in the first row of houses, adjacent to the tracks). Following is a summary of the results of the measurements.

Interior CNEL: California law: 45 dB Measured: 40.8 dB.

HUD Excedence-Time Limits for Interior Noise Levels:

HUD 24-hr. time limit re 55 dBA:	60 min.	Measured:	4 min.
HUD 8-hr. (2300-0700) re 45 dBA:	30 min.	Measured:	10 min.
HUD 24-hr. time limit re 45 dBA:	480 min.	Measured:	43 min.

The project and individual dwellings as constructed were found to have met the requirements of the State of California and the U.S. Department of Housing and Urban Develoment with an ample margin of safety.

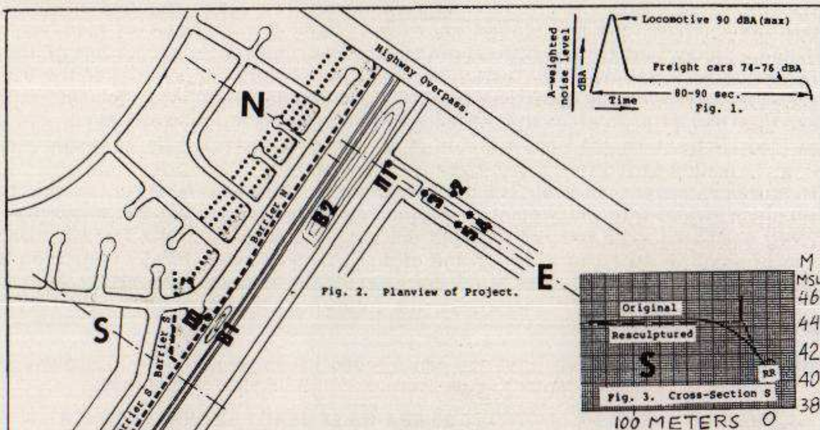

Fig. 1.

Fig. 2. Planview of Project.

Fig. 3. Cross-Section S

Fig. 4. Cross-Section N and E.