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ROLLER COASTER NOISE

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1. INTRODUCTION

A 'country-club' atmosphere is a main attraction of an exclusive residential development abutting a large theme park, where a new tubular-steel roller coaster was one of the main attractions. A number of complaints about noise from the new roller coaster had been received from residents, and increasing pressure was being exerted on the park owner to provide relief from noise produced by the ride.

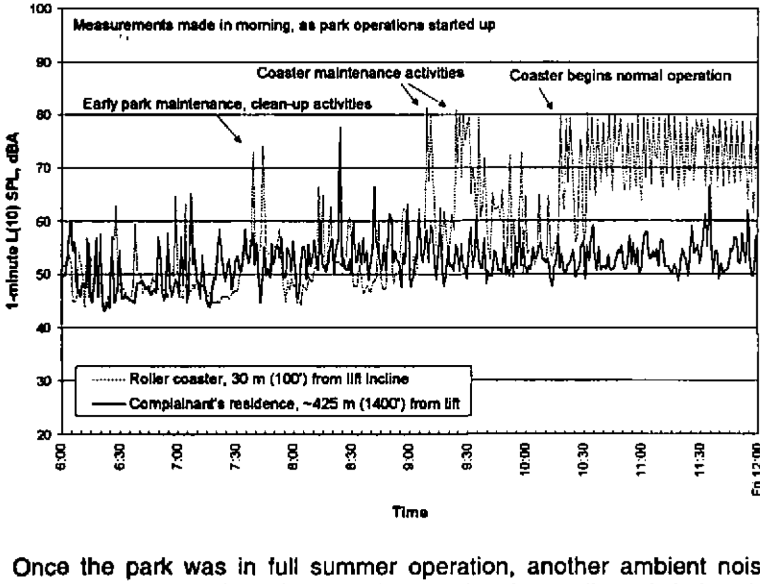
Initial work focused on measuring community noise levels with and without the noise from the park, to assess the magnitude of the noise impact of the roller coaster on nearby residents. Investigations were also made of the specific sources of noise associated with the coaster, with the goal of developing ways in which ride-related noise emissions could be reduced. This paper summarizes the results of these studies.

2. ASSESSMENT OF COASTER NOISE IMPACT

Continuous measurements of ambient environmental noise levels were made at several locations in the residential neighborhood before the park had opened for its full seven-day-a-week summer season. Two automated noise-monitoring devices were set up in the back yards of complaining residents, both located some 425 m (1400 ft) from the coaster; acoustical data collected there was judged to be representative of the ambient environmental noise levels throughout the impacted neighborhood. A monitor was also set up in the park, about 30 m (100 ft) south of the initial lift incline on the coaster, where coaster noise clearly dominated ambient noise levels.

Figure 1 shows a comparison of the one-minute time-histories of "near-peak" (L_{10}) noise levels measured near the ride and at one of the residences over the period immediately preceding and following the opening of the park to the public. Little correlation can be seen between the levels observed at the park—which were *known* to be influenced by the coaster —and levels out in the community. Near the ride, distinct 'spikes' are evident in the measured noise levels which can be attributed to early-morning maintenance activities and, more noticeably, to the 10:20 a.m. startup of the ride. However, no corresponding spikes can be seen in the L_{10} levels measured in the community (similar lack of correspondence was found in the L_{90} background levels, as well). Nevertheless, given the general level of community concern and annoyance with park-related noise, it was judged that a second survey, conducted at a time when background (non-park) noise sources were at their quietest, would be beneficial.

Figure 1
Roller Coaster Noise: "Near-Peak" Sound Levels

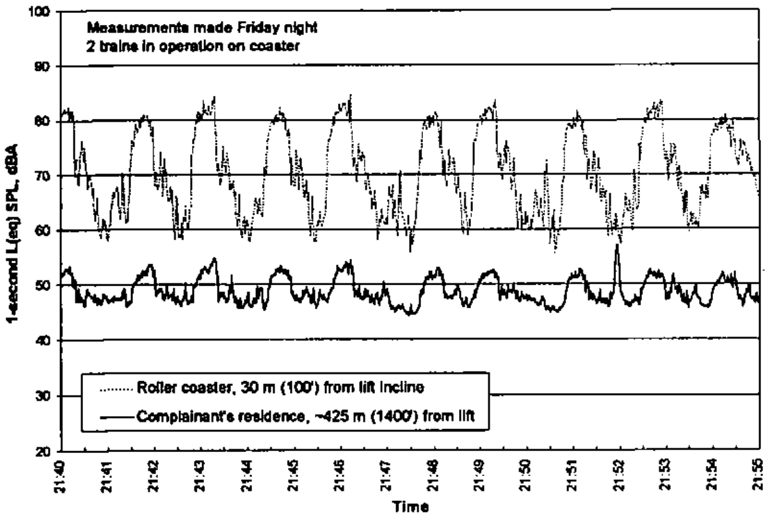


Once the park was in full summer operation, another ambient noise level survey was conducted to supplement the data collected during the initial survey and to gather additional data on the influence of roller coaster noise emissions on noise levels in the community. Measurements were made late on a Friday night, into the period when extraneous (non-park) noise sources had quieted down; it was expected that park-related noise emissions would be less masked by general ambient sounds at this time than they had been during the earlier daytime survey.

The one-minute time-history data on community noise levels collected during the initial survey had failed to provide a sufficiently detailed view of the short-term variations in sound levels to reveal the influence of ride noise on the levels in the community. Therefore, a "high-resolution" view of the variations in sound level as the individual trains of the ride traveled around the track was obtained by collecting one-second time-history data.

Figure 2 shows a representative segment of data measured at two of the monitors. As expected, the highest levels were measured near the ride; within each overlapping 2½-minute ride cycle, the highest levels occurred for the roughly 30-second period that a train was being hoisted up the initial incline. Noise levels increased from the upper 50s to over 80 dBA every time a train was pulled up the lift incline; once the train cleared the lift, levels dropped dramatically (as did the train), until the next train was pulled up the lift. Most telling is the periodic nature of fluctuations in the ambient levels measured at the residence—directly coinciding with the periodic fluctuations measured close to the ride.

Figure 2
Noise Emissions from Roller Coaster vs. Community Noise Levels



Here was clear evidence that the ride was a significant contributor to short-term fluctuations in ambient noise levels in the community. Although existing environmental sounds largely mask its noise during the daytime, coaster noise becomes more evident once these sounds die down in the late evening period. Periodic noise-level fluctuations of some 6-8 dB, directly attributable to the ride, were measured in the community on a "typical" Friday night. Such variations in ambient sound levels could be expected to be judged annoying by many people, thus largely confirming the validity of the neighbors' complaints.

The one-second time-histories served not only to identify the ride as a major noise source, but also to help identify the specific components of the ride that dominated its noise emissions. From the data collected in the community, it appeared that a significant reduction in the perceived intrusiveness of the ride could be realized if a 5-10 dB reduction in lift-related noise could be achieved, which could lead to a substantial improvement in the community's perception of noise from the park.

3. COASTER NOISE SOURCES

Although louder noises are occasionally generated, both by people in the coaster and by mechanical noise at certain points in the ride cycle, the highest sustained noise levels from the coaster were generated during each train's ascent up the initial lift incline—a loud "clackity-clackity" noise is produced from the time the train hits the bottom of the lift to when it clears the top of the first peak.

Anti-rollback mechanism

Of the many possible noise-producing mechanisms comprising the lift, it appears that most of the noise is generated by the anti-rollback device. Under two of the cars in each seven-car train are pawls, or "dogs," which drop onto the teeth of the saw-toothed anti-rollback ratchet track that runs the length of the lift incline, preventing the train from rolling backwards should the lift mechanism fail. Each massive steel dog rotates on a steel pin attached to the undercarriage of the car and drops (by gravity) onto the anti-rollback track. A limit pin attached to the car near the pivot pin restricts full rotation of the dog by acting on the two sides of a C-shaped cutout at the pivot end of each dog.

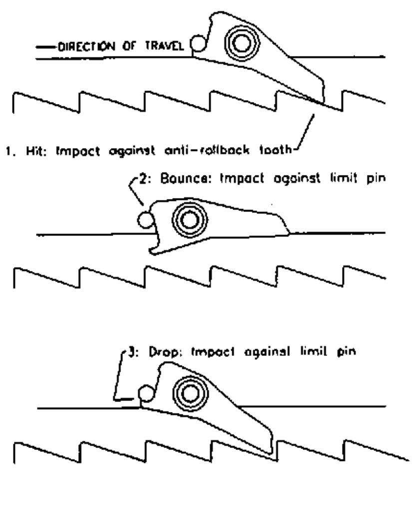


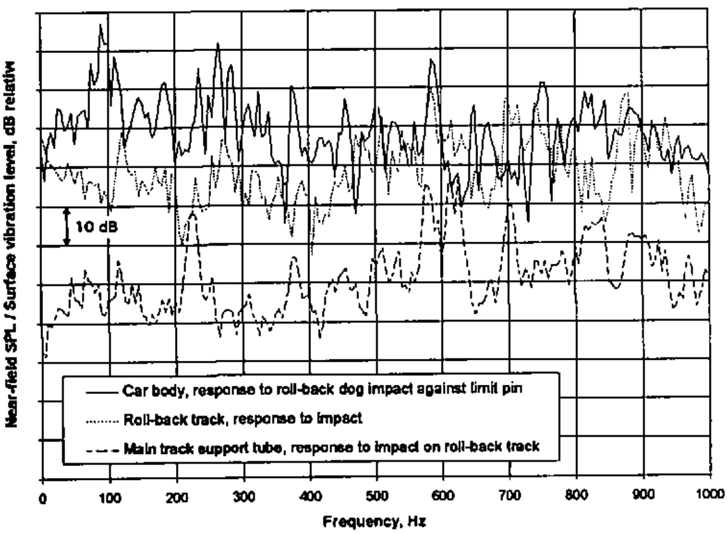
Figure 3
Action of Rollback Dog

As shown in Figure 3, there are three different impact points associated with the normal action of the roll-back dog. As the train is pulled up the initial incline, an impact is produced each time the dog drops into one of the teeth of the anti-rollback track. Impact noise is also produced when the dog bounces off the face of the tooth, rotates about its pivot pin, and hits the limit pin with the upper stop on the C-shaped cutout. As it drops back down from each bounce, the dog hits the limit pin with the lower stop of the cutout before it hits the next ratchet tooth.

Radiation of impact noise. One of the challenges in developing a noise control strategy for the coaster was to assess how the impact energy was radiated, as noise, from the ride. Clearly, the anti-rollback track itself was a prime candidate, because it was the action of the roll-back dogs against the teeth of its ratchet that was largely responsible for much of the impact energy. However, the coaster's tubular steel track structure—rails, rail support tubes, and vertical track supports—combine to form a substantial surface area that could also provide a good radiator of impact noise. The lightweight fiberglass fairings on the cars are also good radiators of impact noise—the fairings can be considered as large sounding boards being driven by the vibratory energy introduced into the stiff undercarriages of the cars by each impact of the rollback dogs.

Simultaneous near-field noise and vibration measurements were made on the anti-rollback track, the track supports, and the car fairings, to assess their relative vibration levels and the relative efficiency with which each component radiated the acoustical energy generated by roll-back mechanism impacts. Vibration levels on the anti-rollback track and the car fairings were found to be in the same general range, while levels on the tubular steel main track supports were found to be somewhat higher. However, as can be seen in Figure 4, both the anti-rollback track and the fairings were found to be highly efficient radiators—much more so than

Figure 4
Coaster Components: Relative Efficiency of Acoustical Radiation



the track supports; the car bodies were found to be even better than the anti-rollback track, particularly in the lower frequencies. In addition, the car fairings have considerably greater radiating surface area than the anti-rollback track. Reducing the radiation of impact noise from the car fairings was thus judged to be the more critical focus of further noise control study.

Earlier noise control experience. Efforts had already been made to reduce the impact of the rollback dogs at the three impact points: a thick coating of resilient urethane was routinely applied to the dog, providing additional cushioning at the impact points and slightly reducing the noise of the original steel-to-steel design.

Although the resilient coating was a step in the right direction, it had several serious deficiencies. Stresses and friction on the urethane caused it to abrade quickly, negating most of the potential benefit of the treatment—reportedly, the dogs needed to be replaced every couple of days because the coating would completely rub off, exposing bare steel where the dog slid along the anti-rollback track; this, of course, created a good deal of extra work for the maintenance crew. From an acoustical standpoint, it appeared that the material used to coat the dogs was too hard: while the coating reduced some of the high-frequency metallic ("clink") sounds, it did not provide sufficient cushioning to reduce the lower-frequency ("clunk") sounds that dominated the audible noise emissions of the ride.

4. RESOLUTION OF THE NOISE PROBLEM

Given the ultimate safety function of the anti-rollback mechanism, extreme caution and conservatism had to be exercised in the development of noise control recommendations for the roller coaster. Several alternative suggestions were made regarding relatively non-intrusive ways in which the peak magnitude of the impacts of the rollback dogs against their limit pins could be reduced. In general, recommendations were driven by the desire to avoid any possible interference with the operational aspects of the existing rollback protection system.

However, the problem was solved by installing a newly-designed anti-rollback system employing an electro-magnetic clutch mechanism that effectively eliminates the impacts which generated the noise that gave rise to the abutting community's noise complaints.