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15 November 2013

Tad Bowman
Red Rocks & Denver Coliseum, Venue Director
City and County of Denver
1245 Champa, 1st Floor
Denver, CO 80204

RE: Red Rocks Amphitheater Noise Analysis

Dear Mr. Bowman,

K2 Audio visited the site of Red Rocks Amphitheater and a nearby residential neighborhood in Morrison, CO, to ascertain the noise concerns for the residents in Morrison due to electronic dance music (EDM) concerts at the amphitheater. K2 visited and performed noise measurements in the amphitheater and in the Morrison neighborhood (near the intersection of Red Rocks Vista Drive and Wood Lane), on three occasions—Thursday, August 1, 2013 for the Knife Party concert (several acts featuring EDM), Sunday, August 4, 2013 for the Doobie Brothers/Steve Miller Band concert, and Friday, August 16, 2013 for the Pretty Lights EDM concert. We subsequently executed a daytime mock-up in the unoccupied amphitheater on the afternoon of September 25, 2013, with simultaneous measurements executed in Morrison.

As part of our scope of work with the City and County of Denver, K2 will later provide recommendations to implement a noise monitoring system. In the meantime, based on our measurements, it has been requested that we recommend noise limits for the yet-to-be-determined monitoring system. With these noise limit guidelines, the City and County of Denver may better execute contracts for the 2014 concert season with stated noise limits in place for promoters and for acts who will perform at the facility.

Consistent across noise measurements taken in 2012 (by C&IH) and August 2013 (by K2 Audio), EDM acts result in elevated low-frequency noise levels in Morrison neighborhoods. Of particular concern are low-frequency noise levels (25 – 80 Hz band frequencies), which are not accounted for in A-weighted (dBA) noise measurements. Levels in these low frequencies were measured at over 75 dB at various times. The implemented monitoring system should monitor the low frequency content in the sound spectrum. The highest recorded noise levels for 1-minute averages in the low frequencies at the front of house mix position was 132 dB.

In Figure 1, one can see that the noise levels in the low frequencies in Morrison track closely the noise levels recorded at the front of house mix position at Red Rocks. There is approximately a 50-55 dB differential between noise levels obtained in the two locations. This leads us to the conclusion that noise levels at the front-of-house mix position should be no more than 50-55 dB louder than acceptable noise levels in Morrison, or approximately

125 dB in the low frequencies at the front of house mix position. This 7 dB drop in level from maximum noise levels of 132 dB for low frequency noise is a clearly noticeable difference and is similar to the drop in level one experiences when a noise source moves twice as far away from the listener.

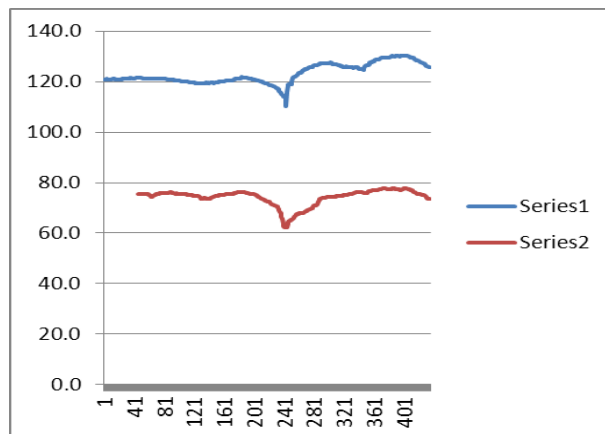


Figure 1: During the performance of Pretty Lights on August 16, 2013, "Series 1" shows the bass frequency Leq noise levels logged at the front-of-house mix position and "Series 2" shows the bass frequency Leq noise levels logged simultaneously in the residential area of Morrison. The horizontal-axis is in seconds starting at 11:00 pm and ending at 11:08 pm; the vertical-axis is in dB (re 20×10^6 Pa.) The Leq's in both series are calculated as 1-minute running averages.

In addition to appropriate Leq levels, the other two factors that should be considered in setting the criteria for the noise monitoring system are the frequency weighting and the length of time for time averaging. We recommend monitoring the sum of the non-weighted 25-80 Hz 1/3 octave bands to account for the frequency content that is causing the most complaints in Morrison.

When the length of time for averaging is increased, the recorded levels also decrease significantly. This is consistent with our tolerance for high levels of volume for only small periods of time. In the case of our measurements of EDM music, we see a 5-9 dB decrease in level going from 1 second averaging to 1 minute averaging, and another 5-9 dB decrease in level going from 1 minute to 10 minute averaging. The longer the time averaging in the monitoring system, the lower the noise limit should be set. This also relates to the local residents' limits of annoyance—the longer the time period, the lower the tolerance for high noise levels. Tight control on the sound engineers can be obtained by setting 1-minute monitoring periods. The one minute averaging also makes it easier for the FOH mixer to monitor and respond accordingly to the monitoring system.

Vibration impact

In order to respond to reports from Morrison residents that their homes were vibrating sympathetically to the music and that it could even be felt in basements, K2 Audio measured the vibration impact of EDM concert-level noise levels on the foundations of two residences in Morrison on Sept. 25, 2013. One residence was at 109 Wood Lane and the other was at the northwest corner of the intersection of Red Rocks Vista Drive and Red Rocks Vista Lane. Although clear levels of vibration were detected in the amphitheater structure at center stage and 6 feet into the audience at stage right when EDM, bass-heavy music was being played through the sound system, there were no appreciable vibration levels detected above the

ambient vibration levels in the foundations of the Morrison residences at the frequencies of concern. This was true regardless of whether the subwoofers were resting on the stage or flown above the stage (decoupled from the structure.) We can conclude that the nature of the sound energy is airborne sound levels and not structure borne. However, it is possible that once airborne sound energy enters into a home, the sound energy can appear to be greater inside the home than outside the home. Further study would be required inside particular Morrison residences to detect the airborne sound levels within the homes due to sound sources at Red Rocks Amphitheater.



Mock-up for vibration and airborne sound measurements on Sept. 25, 2013



Vibration measurement location in the amphitheate



Site of vibration and airborne measurements at Morrison residence on Red Rocks Vista Lane

Summary and recommendations

K2 Audio recommends using enforcing noise limits at the front of house mix position at Red Rocks amphitheater. As requested by Denver Arts and Venues, we are recommending the following noise limits after a given curfew (to be determined by Denver Arts and Venues.)

Time of day	Low Frequency** Leq (1-minute averaging)	Leq, A-weighted (1-minute averaging)
After curfew*	125 dB	105 dBA

*curfew set by Denver Arts and Venues **sum of 25-80 Hz 1/3 octave bands

In the next portion of K2 Audio's services, we will recommend a noise monitoring system to enforce these noise levels. Please contact K2 Audio for any questions or concerns about this report.