Aerial Structure Noise Reduction Effectiveness of Resilient Rail Fasteners

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Resilient rail fasteners have received significant attention at the New York City Transit Authority (NYCTA) and the Washington Metropolitan Area Transit Authority (WMATA) as a means for reducing wayside noise from steel stringer and steel box elevated structures and groundborne noise from subways. Noise and vibration data collected at NYCTA and WMATA indicate that noise and vibration reductions are generally small unless very soft resilient fasteners are used. Very soft fasteners providing good low-frequency performance may exhibit poor isolation or amplify structure vibration at frequencies above 200 to 400 Hz because of resonances in the elastomer pad or top plate. Laboratory tests of the forward transfer impedance of resilient rail fasteners indicate that these secondary resonance frequencies are about 600 to 800 Hz for the softest fasteners tested for the NYCTA and WMATA systems. A laboratory test procedure has been developed into an acceptance test procedure for resilient fasteners supplied to the WMATA system as noise-reducing fasteners for either subway or elevated structure use. This procedure represents a substantial change in acceptance test procedures that have heretofore focused on physical properties related to stability and safety of the fasteners. Data are presented illustrating measured noise reductions and laboratory test results.

Resilient rail fasteners have received significant attention for controlling elevated structure noise and groundborne noise and vibration from subways. Early work included field measurements and evaluation of prototype fasteners for the San Francisco Bay Area Rapid Transit System (BART) (*1*). Field tests were conducted by the Toronto Transit Commission (TTC) at the Yonge Subway Northern Extension tunnels to determine the effect of fastener stiffness reduction on groundborne noise (*2*). The New York City Transit Authority (NYCTA) has completed testing and evaluation of several candidate rail fasteners for use on steel elevated structures (*3*). There have been notable contributions in the area of predicting wayside noise and vibration. These include a review of various prediction methods for steel elevated structure (*4*), and a detailed prediction method (*5*) that includes an effect attributable to rail fastener elastomer standing wave resonances.

This paper discusses some of the noise control results obtained at the Washington Metropolitan Area Transit Authority (WMATA) Metro with resilient direct fixation rail fasteners at a section of a steel box concrete deck aerial structure. Results for the NYCTA solid web steel stringer and wood tie deck elevated structures (*3*) are not yet available for publication. A laboratory test procedure was developed for evaluating the effective stiffness of resilient fasteners for frequencies extending up to at least 1000 Hz. The procedure has since been developed into a laboratory acceptance test for procurement of resilient noise reducing fasteners at WMATA. A discussion of the procedure is provided.

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WAYSIDE NOISE AND VIBRATION FROM ELEVATED STRUCTURES

Wayside 1/3 octave band noise levels measured at 1.5 m above grade near two elevated structures are presented in Figure 1. The first spectrum is of noise produced by WMATA Metro trains traveling at approximately 60–70 km/hr on a concrete deck steel box aerial structure with sound barrier wall. The second is of wayside noise produced by 40 km/hr Chicago Transit Authority (CTA) trains on a wood tie deck solid web steel stringer elevated structure. Both spectra exhibit a general roll-off above about 500 Hz. The noise from the CTA structure exceeds that from the WMATA structure by 5 to 15 dB above 125 Hz. Below 63 Hz, the radiation efficiency of the CTA solid web steel stringer decreases with decreasing frequency, relative to that of the WMATA steel box, producing a large disparity between low-frequency noise levels for these two basic structural configurations.

Our experience at the NYCTA suggests that virtually the entire spectrum shown for the CTA elevated structure is attributable to stringer-radiated noise, though Remington's (1985) prediction model suggests that the wood tie deck is also a significant source. For solid web steel stringers, the wayside *A*-weighted noise levels are determined by the broad peak at about 500 Hz. Resilient rail fasteners selected for reducing stringer vibration and radiated noise at steel elevated structures must, therefore, be effective beyond 500 Hz, placing significant demands on fastener design.

Figure 2 illustrates the vibration reduction effectiveness of three relatively soft resilient rail fasteners field tested at the WMATA system. These include the LORD #79, the Clouth Cologne Egg, and the Advanced Track Dual-Stiffness Egg, with dynamic stiffnesses of 18 MN/m, 14 MN/m, and 9 MN/m, respectively. The vibration reductions are relative to vibration measured for the standard WMATA fastener, and were obtained by measuring steel box girder vibration at the bottom and sides before and after installation of each of the fasteners. The data are thus good comparisons of fastener performance in reducing structural vibration.

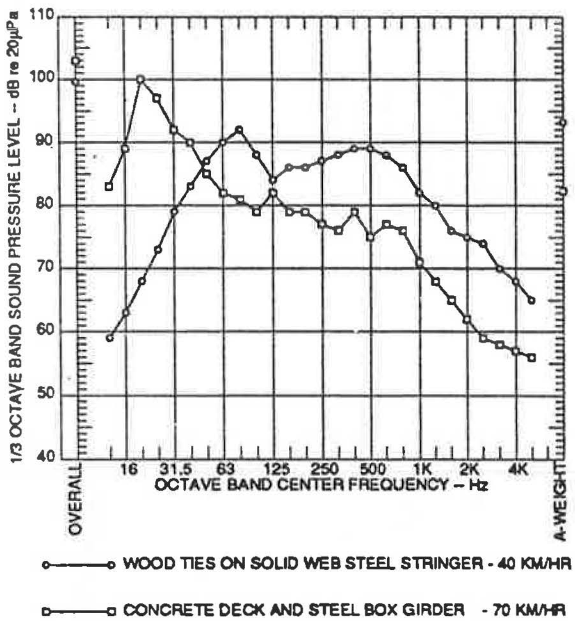

FIGURE 1 Aerial structure noise at 1.5 meters above grade.

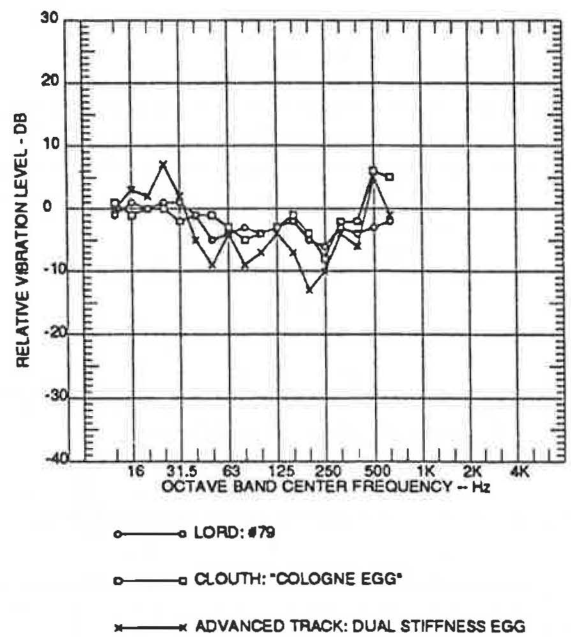

FIGURE 2 Vibration reductions relative to standard WMATA fastener.

The results given in Figure 2 indicate that all of the soft fasteners produced significant vibration reductions from 63 Hz to about 315 or 400 Hz; the Dual-Stiffness Egg provided the greatest vibration reduction. At 25 Hz, some amplification of vibration with the Dual-Stiffness Egg may occur relative to the standard WMATA fastener. Both the LORD 79 and Clouth Egg give essentially similar results. The low-frequency behavior of the various track fasteners is well predicted by a model of an elastically supported rail and unsprung wheel set mass with a prescribed wheel/rail roughness (*6*).

Little or no vibration reductions were obtained at 500 Hz. Because this is an important frequency for steel elevated structures, characterizing fasteners at these frequencies and attempting to understand why a fastener may or may not be effective at high frequencies is important.

LABORATORY TEST PROCEDURE

A laboratory test procedure has been developed for studying the high-frequency vibration isolation effectiveness of resilient rail fasteners. The test determines the forward transfer impedance of a fastener under representative static loads. The forward transfer impedance is the ratio of the Fourier transforms of the transmitted vertical force to the rail web vertical velocity with baseplate blocked. The test, therefore, includes the effect of rail flange and fastener top-plate bending.

Figure 3 is a schematic of the test apparatus. The machine is supported on pneumatic springs, and weighs approximately 680 kg. The base is solid steel, weighing approximately 550 kg, and exhibits a fundamental vibration mode at about 1200 Hz. The fastener is bolted to a 1.9-cm thick aluminum plate and placed on a flat load cell that integrates the transmitted force over the load cell area. A short section of rail is placed in the fastener, with an accelerometer mounted in the plane of the rail web. A second accelerometer is mounted beneath the inertia base to provide an inertial reference signal that can be used to extend the low-frequency range of the test. Static loads are applied to the rail and fastener assembly with pneumatic springs. The fastener's forward transfer impedance is measured by tapping the top of the rail and measuring the transfer function between transmitted force and rail web velocity with a dual-channel Fast Fourier Transform (FFT) analyzer.

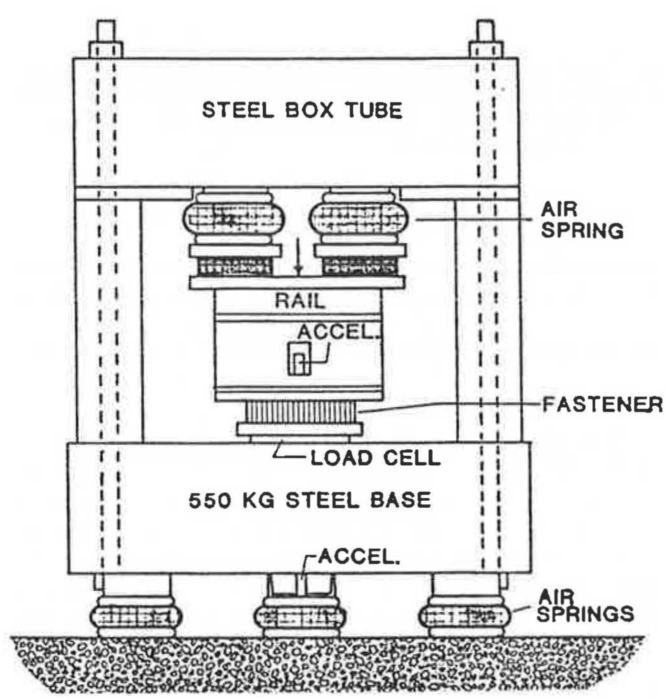

FIGURE 3 Resilient rail fastener test apparatus.

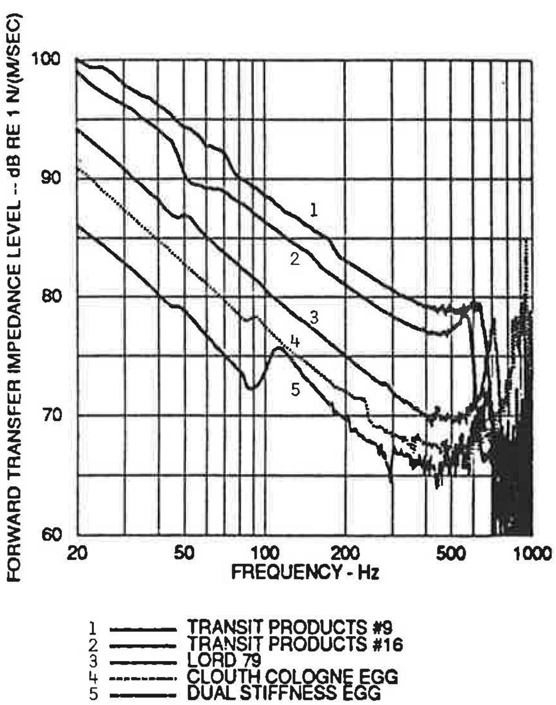

FIGURE 4 Comparison of various fasteners under 13 KN static load.

Forward transfer impedance functions for various fasteners are presented in Figure 4. Represented are two WMATA TW-10 prototype fasteners manufactured by Transit Products, Inc. (TPI #9 and #10) and three "soft" fasteners: LORD #79, Couth Cologne Egg, and the Advanced Track Dual-Stiffness Egg. The two WMATA TW-10 prototype fasteners are substantially stiffer than the soft fasteners, as indicated by their high transfer impedance magnitude levels. The Dual-Stiffness Egg exhibits the lowest dynamic stiffness over the entire frequency range shown, consistent with the results of Figure 2.

Most of the fasteners exhibit a spring-like characteristic up to about 200 or 300 Hz. The Dual-Stiffness Egg, however, exhibits a resonance at about 100 to 125 Hz, probably because of the elastomer suspended beneath the top plate. Above 300 Hz, the forward transfer impedance functions deviate significantly from a "spring-like" characteristic. The TW-10 prototypes exhibit resonance peaks at about 570 Hz and 600 Hz, and the remaining fasteners exhibit peaks at about 700 Hz. The forward transfer impedance of the Dual-Stiffness Egg is given in Figure 5 for a series of static loads. At low static load, the resonance frequency for the Dual-Stiffness Egg drops significantly to about 630 Hz. This was observed for the Clouth Egg also. At high static loads, the dynamic stiffness of the Dual-Stiffness Egg rises, eventually exceeding those of the LORD #79 and Clouth Fasteners.

The measured steel box girder vibration reductions illustrated in Figure 2 are minimal at about 125 Hz, and some amplification is evident at 500 Hz. The low isolation at 125 Hz observed for the Dual-Stiffness Egg may be related to the resonance at about 125 Hz observed in its forward transfer impedance. The resonance at about 620 Hz observed for the Clouth and Dual-Stiffness Eggs at low static load may explain the slight amplification of structural vibration at 500 Hz. More testing is desirable to verify these relationships.

FASTENER TOP PLATE BENDING

Figure 6 illustrates the theoretical forward transfer impedances of two fasteners idealized as uniform steel plates supported on elastic foundations. One of the plates is 1.27 cm thick, supported on an elastic foundation giving a total static stiffness of 25 MN/m. The second curve is of a 1.905-cm thick steel plate supported on an elastic foundation giving a total

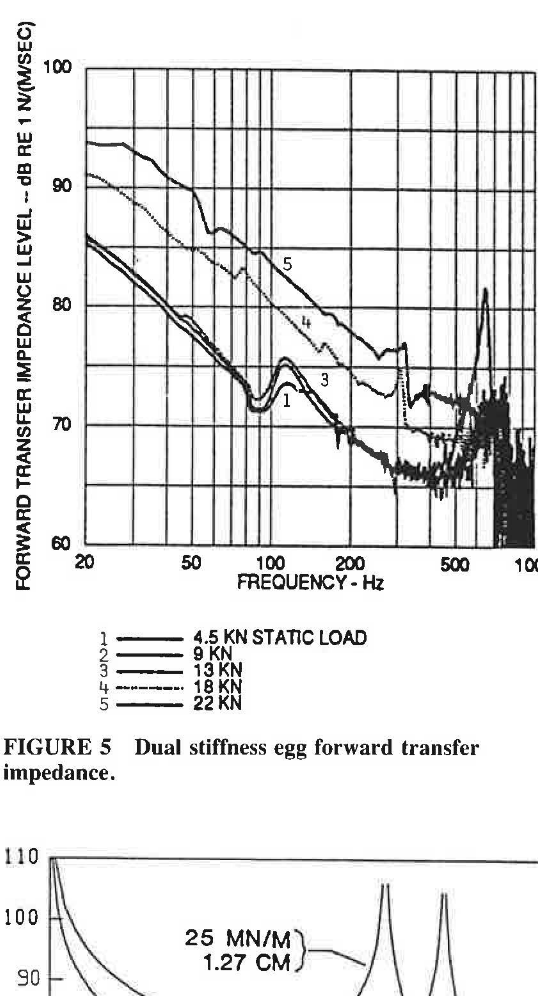

FIGURE 5 Dual stiffness egg forward transfer impedance.

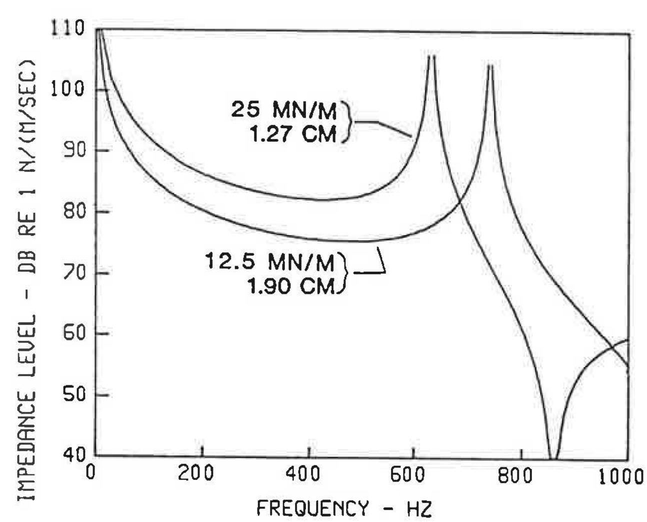

FIGURE 6 Effect of fastener stiffness reduction and top-plate thickness on forward transfer impedance.

static stiffness of 12.5 MN/m. Top-plate dimensions are 30.48 cm by 17.78 cm. The lower stiffness represented by the forward transfer impedance of the "soft" fastener would not have been obtained above 500 Hz if the top plate thickness were not increased. Without thickening the top plate, the peak in the forward transfer impedance would have been about 550 Hz.

The ratio of dynamic-to-static stiffnesses of the fasteners are also influenced by bending of the plate. At low frequencies, top-plate bending reduces total fastener stiffness relative to that obtained by rigid body deflection of the top plate. At the resonance frequency associated with the top-plate mass on the elastomer, the top-plate motion is rigid, resulting in increased dynamic stiffness relative to the low-frequency case. Thus, fasteners should be designed with as rigid a top plate as practicable to reduce the ratio of dynamic-to-static stiffness at audio frequencies, and maintain the frequency of the forward transfer impedance peak as high as possible, preferably about 1000 Hz. Rail flange stiffness contributes to top-plate stiffness, and use of heavy rail should be favorable to lightweight rail.

CONCLUSION

The experience gained at WMATA indicates that elevated structure noise can be reduced by selecting resilient rail fasteners of stiffness 9 MN/m to 18 MN/m. Effective performance over the most significant frequency range of wayside noise, however, requires that top-plate bending resonance frequencies be maintained as high as possible, preferably in excess of 1000 Hz. Stiffening the top plates will also lower the ratio of dynamic-to-static stiffness, desirable for elevated structure noise control.

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