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Reduction of Noise from Composite Steel/Concrete Aerial Structures by Damping Steel Plates

George Wilson^a and Francis Kirschner^b

^aWilson, Ihrig & Associates, Inc., 5776 Broadway, Oakland, CA 94618, USA

^bFGK Consulting, Inc., East Hills, Long Island, NY 11576, USA

gwilson@wiai.com

Noise radiated from steel girders at bridges and aerial structures has been a long standing problem for steel wheel and rail systems. During the initial design period for the San Francisco Bay Area Rapid Transit System, 1/7 scale models, one with steel girder and concrete deck and one with concrete deck and girder, were constructed in 1964 and tested with and without damping material on the steel girder plates. A full scale mock-up of a composite structure was then constructed and a test track installation with both types of aerial structure was constructed in 1965. With full homogeneous damping applied to the steel girder plates, both the scale model and full size mock-up showed about 9 dBA reduction in radiated noise and 5 to 9 dB reduction at low frequencies. Most of the BART aerial structures are concrete girder but a few large-span structures with undamped steel girders resulted in low frequency noise which did cause community complaints. A lower cost design with partial area constrained layer damping was developed in the 1970's and successfully applied to composite steel/concrete aerial structures to achieve 9 dB reduction of low frequency noise for the Atlanta rail transit system.

1 Introduction

In the 1960's and 70's in the United States there was a resurgence of interest in public transit systems. During this period several new rail transit systems were designed and constructed. Since there had not been any new systems in the US since the 1930's, the planners and designers for the proposed new transit facilities completed a number of surveys and investigations to determine what were considered the principal problems at existing systems. Almost universally, noise was identified as a major problem. As a result, control of noise experienced both by patrons and wayside neighbors was accepted as a major design parameter for the new systems.

Because noise radiated from steel girder aerial structures and bridges was a long-standing problem for rail transit systems, to minimize noise some of the designers decided to use all-concrete structures, i.e., both concrete deck and concrete girder. However, because concrete girder structures are heavier and more limited in span length than steel girder structures, there was considerable motivation to develop a means for using steel girders and controlling the noise to the same degree that the concrete structures minimize noise.

While some of the system designers relied on conventional design configurations and demonstrated technology, the San Francisco Bay Area Rapid Transit System, BART, commissioned studies to develop and evaluate new technology, including constructing a test track which included both all-concrete and composite steel/concrete aerial structures. For the steel girder noise control the studies also included noise testing of approximately 1/7th scale model concrete and composite steel/concrete aerial structures with and without damping completed by the Korfund Dynamics Corporation. To further demonstrate the benefits of damping, noise and vibration measurement studies of a full scale mock-up composite steel girder concrete deck structure were completed by Stanford Research Institute in cooperation with The Soundcoat Company, Inc. The full scale mock-up was tested for wayside noise radiation with homogenous damping material of 1/2 to 1 times the plate thickness on the entire area of inner surfaces of the steel plates. This treatment resulted in significant reduction of noise radiated from the composite aerial structure.

Because full area damping was not adopted for the BART composite structure girders, there was significant radiated low frequency noise, below 150 Hz, which did cause

complaints during early operations. This result led to further studies which were completed in the 1970's by the Soundcoat Company, Inc. in cooperation with the American Iron & Steel Institute. This resulted in the development of finite element analysis computer programs for determining the modal characteristics and for optimizing partial area *constrained layer* damping for the steel girder side and bottom plates. This provided the basis for the design of a successful partial area constrained layer damping configuration which reduced the radiated wayside noise to essentially the same as for a concrete girder at lower cost than for full area damping treatment.

2 Scale Model Study

The model study program intended to develop quantitative information on noise radiation by composite steel/concrete aerial structures and all-concrete structures consisted of noise testing in an enclosure, as shown by Figure 1, with a top opening to accommodate the box girder bridge models which were 3.5 m length. The enclosure permitted measurement of structural noise radiated from the girder and bottom of the concrete deck without interference from airborne noise created by the impact on top of the concrete deck. A standard ISO R140 tapping machine was used to provide a calibrated and equivalent impact force for the two models tested. Both the brass hammers and the rubber hammers were used.

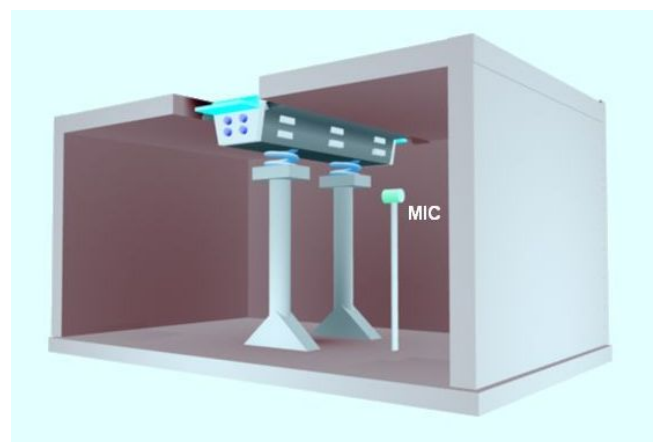


Fig. 1 Test Chamber with Scale Model
Prestressed Concrete Aerial Structure

Figure 2 indicates schematically the cross-sections for the all-concrete girder and the composite concrete deck and steel girder structure. Based on data from Reference [1], Figure 2 also presents the noise generated in the test facility

by radiation from the all-concrete structure for the range from zero to maximum prestressing. This test confirmed the previous qualitative conclusions that increasing prestress on the concrete structure increases the noise radiation. Figure 2 also presents the noise radiated (all other conditions being the same) for the composite structure with no damping applied and with full area homogenous visco-elastic damping material of thickness equivalent to the steel plate thickness. As is apparent, the damping was effective at reducing noise radiated by 9 to 12 dB in the mid and high frequencies and by 4 to 5 dB at low frequencies, below 150 Hz. At the mid-frequency range the damped steel girder resulted in about the same noise level as for the prestressed concrete but with a lower radiated noise level at the high frequencies, above 300 Hz. However, at lower frequencies, the steel girder, even with damping, radiated 10 to 12 dB higher noise level than the concrete girder.

The noise testing with the rubber hammers indicated very large reduction of the higher frequencies, above 300 Hz, but essentially no change at the lower frequencies, below 150 Hz. This was significant in showing the importance of using resilient rail fasteners to reduce the amplitude of higher frequency noise transmission from the rail to the supporting aerial structure.

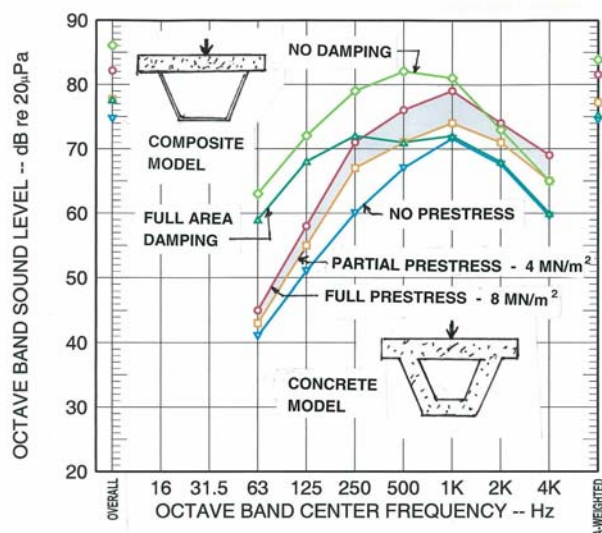


Fig. 2 Noise Radiated by 1/7 Scale Model Aerial Structures – Direct Impact Excitation

3 Full Scale Mockup Test

To better determine the effectiveness and comparative performance of a composite concrete deck steel girder aerial structure, the American Bridge Division of U.S. Steel Corporation constructed a full scale concrete and steel bridge girder 28 m long. Testing was completed in cooperation with the Korfund Co. at and by the Stanford Research Institute in Palo Alto, California. For the acoustic tests, the excitation was by a pneumatic vibrator providing 39 kN impact force. Sound measurements were made along a 15 m radius arc transverse to the girder which was placed on piers over hard ground.

The Type 80A damping material provided by Korfund was applied to the interior surfaces of the 5/8" thick side and bottom steel plates; applied first in two layers 1/8" thick

over the entire area and then an added layer of 1/8" thickness to 3/8" thickness was added with the thicker material at locations indicated to be critical by an analysis of vibrational modes. As for the scale model tests, this was not a constrained layer damping but only homogenous damping material applied to the full area of the inner steel surfaces of the girder.

The first tests were evaluation of the noise radiated by the composite steel/concrete girder before any damping material was applied to the metal plates. For comparison with the concrete structure a similar set of measurements were made with the same pneumatic vibrator on a section of prestressed concrete aerial structure girder constructed at the original BART test track. The results from these tests are presented on the top part of Figure 3 [2, 3]. The main conclusion from this comparison was that the sound level spectra radiated by the two structures were very similar, except for the low frequencies, below about 150 Hz, where the undamped composite/steel concrete girder radiated significantly higher sound levels than the prestressed concrete girder. This basically confirmed the results from the scale model tests. A later series of tests, as shown by the lower part of Figure 3, comparing the wayside noise with transit car excitation also indicated similar noise spectra at 23 m from the structure except that the transit car excitation produced 6 to 8 dB higher sound levels in the frequency range below about 150 Hz [4]. As is evident, the lower frequency sound, below about 150 Hz, radiated by the undamped steel structure is substantially greater than for the all-concrete girder, whereas the higher frequency noise was essentially the same for both.

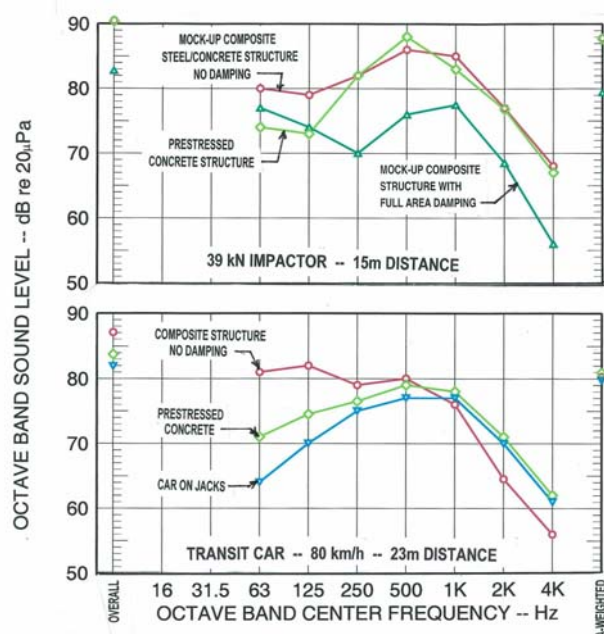


Fig. 3 Noise Radiated by Full Scale Aerial Structures with Direct Impact and With Transit Car Excitation

Acoustic tests for both the damped and undamped girder were completed with the impactor mounted on a rail first directly attached and then with rubber pads under the rail to simulate the vibration transmission reduction which was expected from use of resilient rail fasteners. It was found that in general the rubber pads resulted in noise level reductions of 8 to 12 dB, primarily in the range above 150

Hz. Similarly, the application of full damping treatment to the girder reduced sound levels by 8 to 12 dB at frequencies above 150 Hz. At the lower frequency range, below 150 Hz, the damping achieved 4 to 5 dB reduction of radiated noise.

The testing by Stanford Research Institute did include measurements with a transit car passing by on two types of aerial structures included in the BART test track structures. One was a structure with composite steel/concrete deck and the other was a prestressed all-concrete structure. The wayside noise from both structures was measured at a distance of about 23 m from the track centerline with the transit car operating at about 80 km/h. The lower part of Figure 3 indicates the results of the noise measurements for both types of structure at a distance of about 23 m from the track center and 4.5 m above grade, i.e., approximately horizontal from the bottom of the girder. There was substantially greater noise from the undamped steel girder at low frequencies, comparable noise at the mid range and somewhat less noise at frequencies above about 800 Hz for the composite structure. In this case the mid and higher frequency noise was definitely dominated by noise from the transit car propulsion system and from the rail. The difference of the high frequency noise for the composite structure is predominantly due to a different degree of shadowing by a wider deck. To demonstrate the effect of the transit car noise on the overall results, Figure 3 includes a measurement with the transit car on jacks with traction system and all auxiliaries operating at the same speed as for the passby tests.

4 Constrained Layer Damping of Steel Girders

The high cost of complete coverage of the interior surfaces of steel girder plates either with homogenous damping material of comparable thickness to the plate, or with constrained layer damping, discouraged the use of damping for reducing the low frequency noise characteristic of the steel girders. While the majority of all aerial structures at the BART system were concrete girder, it was necessary to use steel girders at bridges or long spans required to cross surface roadways or due to other factors interfering with placement of support columns at relatively frequent intervals. Because of the low frequency noise that occurred at the undamped composite steel/concrete structures, there was considerable motivation to develop a more economical partial area constrained layer vibration damping treatment for future aerial structures. This was undertaken by the Soundcoat Company in 1975, sponsored by the American Iron & Steel Institute with the final report presented in October 1976, [5].

The detailed study by the Soundcoat Company, Inc. resulted in the development of two finite element analysis computer programs. A program titled "SAP-IV" provided for identifying the normal modes and the frequencies of the normal modes. Once these characteristics are known, the effect of damping treatment on the suppression of dynamic response over selected frequency bands can be evaluated. A second program, denoted "SSDP-II" was developed which permitted optimization of a partial coverage damping treatment. The proposal was then to identify the detailed design requirements for a partial area constrained layer

damping treatment with 30% to 40% coverage of the steel plates. The final report on this study, [5], presents the detailed analysis of a steel box girder as proposed for the Metropolitan Atlanta Rapid Transit system, MARTA. This girder was of 36 m length with concrete deck, 1.6 m height side plates and 2.1 m width bottom plates. The side plates were 17 mm thickness and the bottom plate varied from 50 mm at the center to 25 mm at the end of the span.

Using the computer programs, the girder structure was analyzed section-by-section to obtain a detailed evaluation of the natural mode frequencies and shapes over the frequency range from about 2.5 Hz to 200 Hz. A damping patch arrangement was then developed from study of the mode shapes. The initial analyses developed the results for a 30% and a 40% area coverage. Figure 4 is an example of the side and bottom treatment areas. Further analyses were done to identify other optimal damping treatments, having about 25% to 40% coverage and which achieved better results than the originally derived patch treatment.

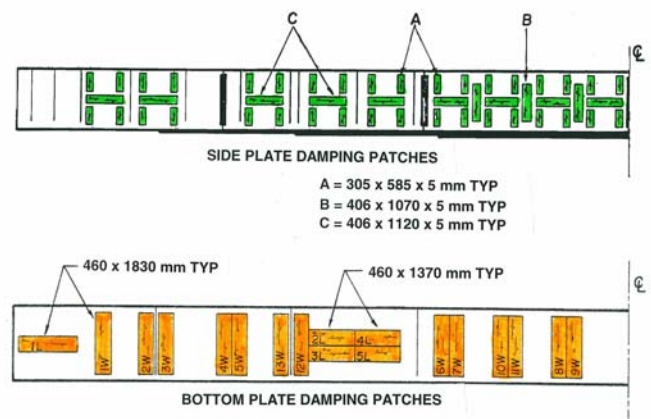


Fig. 4 Example of Optimized 40% Area Damping Patches for MARTA Steel Girders

Using the results from this finite element analysis, a design was developed for the MARTA aerial structure to provide damping for the steel box girder. Figure 5 presents a cross-section of the aerial structure and the details of the damping treatment applied to the girder plate. Figure 6 is a photo showing the damping treatment in place before the concrete deck was placed.

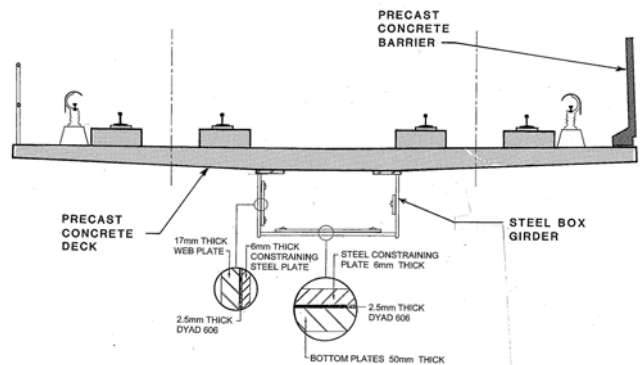


Fig. 5 MARTA Aerial Structure with Steel Girder and Constrained Layer Damping

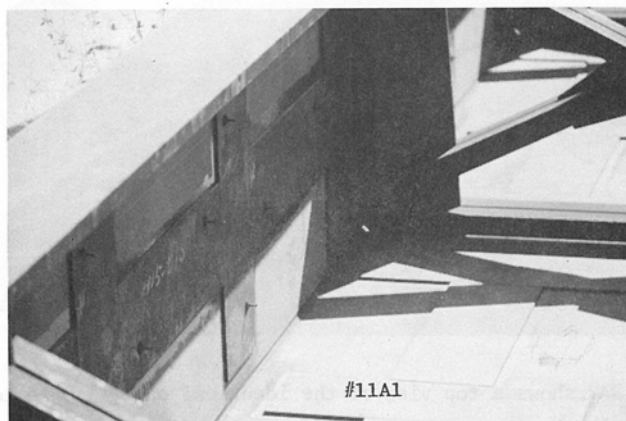


Fig. 6 Photo of Constrained Layer Damping Patches
At MARTA Steel Girder Structure

Because even the approximately 40% coverage with constrained layer damping is an expensive addition to the aerial structure, the damping treatment was applied only to aerial structures located in noise-critical areas such as a nearby residential area. The standard steel structure without damping was used in other areas. As a result, it was possible to make detailed wayside noise measurements of both the damped and the undamped structure.

Figure 7 presents data obtained from the finished MARTA aerial structures showing the noise level at 15 m from the structure for both the damped and undamped case [7, 8]. As is apparent, the damping did result in a reduction of the low frequency radiated noise by 6 to 9 dB. While this had only a small effect on the outdoor A-weighted sound level, the real significance of this reduction is for sound transmitted into a nearby building. Inside a neighboring building, the low frequency noise becomes dominant and the benefit from the damping treatment is substantial.

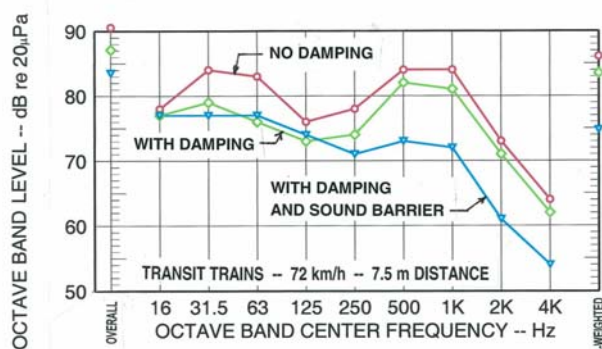


Fig. 7 Noise Levels from MARTA Composite Aerial
Structure without Damping and with Damping
both with and without Sound Barrier Wall

One of the important factors to note from the data presented on Figure 7 is that the reduction of noise radiated at the higher frequencies from the steel girder plates provides for full effectiveness of a low profile sound barrier wall at the edge of the aerial structure deck. Without a sound barrier wall, for both the damped and undamped structure measurements, the noise from the transit vehicles and, to some extent, wheel and rail noise dominate the noise levels above about 250 Hz. With the sound barrier in place, the reduced mid and higher frequency noise from the damped

girder plates allows the sound barrier wall to be fully effective in reducing the overall airborne noise from the transit vehicles.

Another type of measurement which demonstrates the effectiveness of the constrained layer damping in reducing plate vibration levels with accompanying reduction of noise radiation is the vibration measurements on the steel girder which were performed at the same time as the noise measurements. Figure 8 presents the average of the vibration levels measured on the side and bottom plates of the steel girder with the trains passing by at 72 km/h. As is evident on the chart, the reduction of vibration levels is almost uniformly in the range of 9 to 12 dB over the frequency range above about 50 Hz. At frequencies from about 12 Hz to 50 Hz, the reduction is 5 to 6 dB. At frequencies below about 12 Hz, the effect of the damping on the longer wavelength modes is diminished so that there is reduced difference between the damped and undamped structure at frequencies below 4 to 8 Hz. Fortunately, at those low frequencies the excitation from the transit cars is also very low so that there is no emphasis of very low frequency sound from the structures.

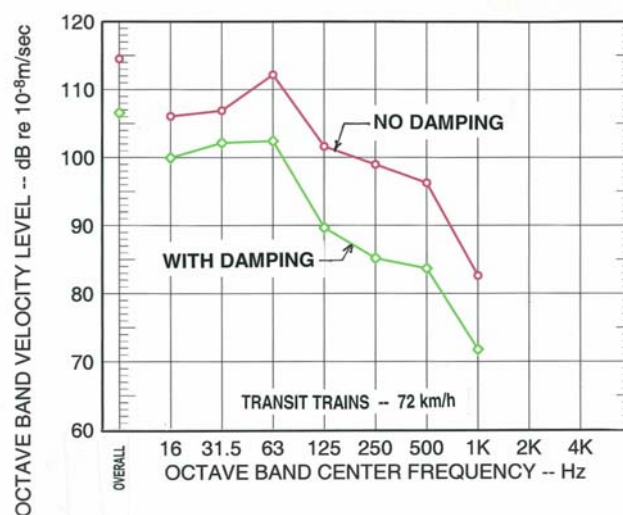


Fig. 8 Measured Average Vibration Levels
For MARTA Aerial Structure Girder

Figure 9 is a photograph of a MARTA aerial structure showing the box steel girder and the concrete deck. The photo is at a location where the structure has a transition from undamped steel girder to damped girder with sound barrier wall.

5 Conclusions

From a development program which took place over a period of about two decades, an economically and technically feasible design for effective damping of the steel girder plates on composite steel concrete aerial structure girders was identified. This design was applied to steel girder structures of the Metropolitan Atlanta Rapid Transit Authority system in noise sensitive community areas and achieved both low frequency and high frequency noise levels similar to those radiated by an all-concrete structure. Further, because of the effectiveness of the damping in reducing radiated noise, it was possible to

obtain a full 9 dBA noise reduction from low profile sound barrier walls installed on the edge of the concrete deck structure.

The demonstrated effectiveness of the partial area constrained layer damping treatment provides a basis for designers of aerial structures and bridges to make use of the structural and cost advantages of steel girders without the higher radiated noise levels traditionally expected. In fact the results of the comparisons with prestressed concrete structures indicate the potential for lower overall sound levels when sound barrier walls are used to reduce airborne noise from the transit vehicles.



Fig. 9 MARTA Composite Steel/Concrete Aerial Structure at a Transition from Undamped to Damped With Sound Barrier Wall

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