Chapter 4

Soft-Mounted Locomotive Cab

Upon analyzing the modifications mentioned in the previous chapter, it became obvious that a major modification to the cab structure is necessary in order to sufficiently influence the cab noise and vibrations. This chapter includes different soft-mounting techniques, the process of soft-mounting the cab, and the tests conducted on the soft-mounted cab. It further includes a comparison between the soft-mounted and hard-mounted cab for cab acceleration levels.

4.1 Soft-Mounting Techniques

As was discussed in Chapter 1, soft-mounting the cab presents an effective approach to reducing interior noise and vibrations. The mounts effectively work as choking points for the vibration energy. They prevent the energy from reaching to the cab structure and, therefore, can significantly reduce vibrations, as demonstrated in many vehicle applications.

The common methods of resiliently mounting a structure include the use of:

- Elastomeric mounts
- Air springs
- Fluid mounts
- Active mounts

Each of these elements will be discussed in more detail next.

4.1.1 Elastomeric Mounts

Elastomeric mounts have been used extensively in reducing noise, vibration, and harshness (NVH) since the 1930’s. As shown in Fig. 4.1, an elastomeric mount is typically a combination of bounded elastomer and metal. The elastomer is generally attached to the metal through a high-pressure and high-temperature bonding process.

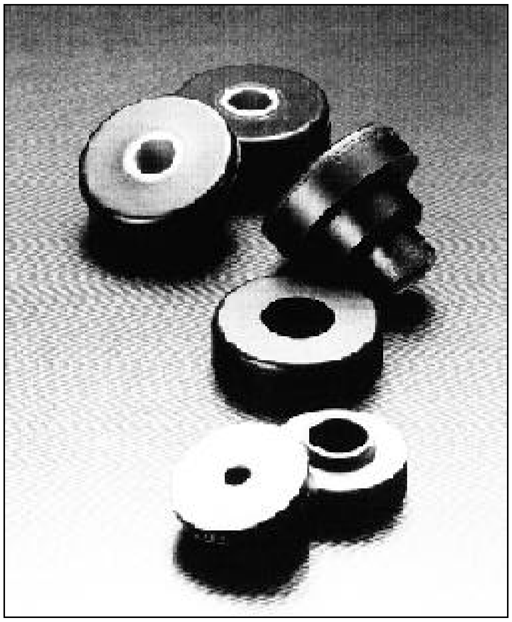


Figure 4.1 Typical Elastomeric Mounts [after 32]

The elastomer, as well as the metal and the bounding agent that are used in elastomeric mounts, must be able to withstand the environmental elements, such as temperature variations, cleaning agents, grease, oil, and other contaminants that are often present in vehicles. Furthermore, the mount must be able to support the static weight of the mounted component (i.e., spring body) and also provide dynamic isolation.

The design of elastomeric mounts often involves choosing a mount configuration that satisfies the envelope, environmental, and life requirements. The mount must also provide the proper compromise between the isolation and static load-carrying capability. To support the static weight of the suspended component, the mount must be made sufficiently stiff. For dynamic isolation, however, the mount must be designed as soft as possible. Therefore, mount designers must determine the dynamic input and its frequency composition so that the resonance of the suspended body sitting on the isolation is at a sufficiently low frequency.

This low frequency allows the isolation system to attenuate response to forcing functions that are 1.414 times this mounted resonance frequency.

Once they have determined the input frequency range, mount designers select the mount stiffness such that it is rigid enough to carry the load, and yet soft enough to offer isolation in the frequency range of the input.

4.1.2 Air Springs

Air springs were developed during the 1930’s at about the same time as the elastomeric pad. As shown in Fig. 4.2, the air spring is a carefully designed rubber bellows that contains a column of compressed gas. The air spring elasticity is generated from the gas compression. The rubber is not designed to support load or provide force; this is accomplished by using pressure as the force generation medium. The ability of the spring to support a load depends on the effective area, which is found by dividing the load supported by the gas pressure at a given position. Spring rates may be varied by changing the effective area and/or pressure [33].

Figure 4.2 Typical Air Spring [after 33]

As compared to elastomeric mounts, air springs have a relatively linear spring rate and are able to provide much larger stroke (sometimes by as much as 100 times more stroke). Further, they can be designed to weight less than elastomeric mounts. Air springs, however, have a lower weight-carrying capability than elastomeric mounts, and their spring rate can change with temperature variation. Furthermore, air springs offer no shear stiffness, unlike elastomeric mounts that can be designed with fairly large shear stiffness.

4.1.3 Fluid Mounts

A fluid mount is simply an elastomeric mount with internal cavities that are filled with fluid. The fluid is able to travel between the cavities (at least two) through a track that can be internal or external to the mount. In the case of a fluid mount with an internal fluid track, the mount is indistinguishable from a regular elastomeric mount. Figure 4.3 and 4.4 show a few typical fluid mounts.

Figure 4.3 Typical Fluid Mounts With Internal [after 34]

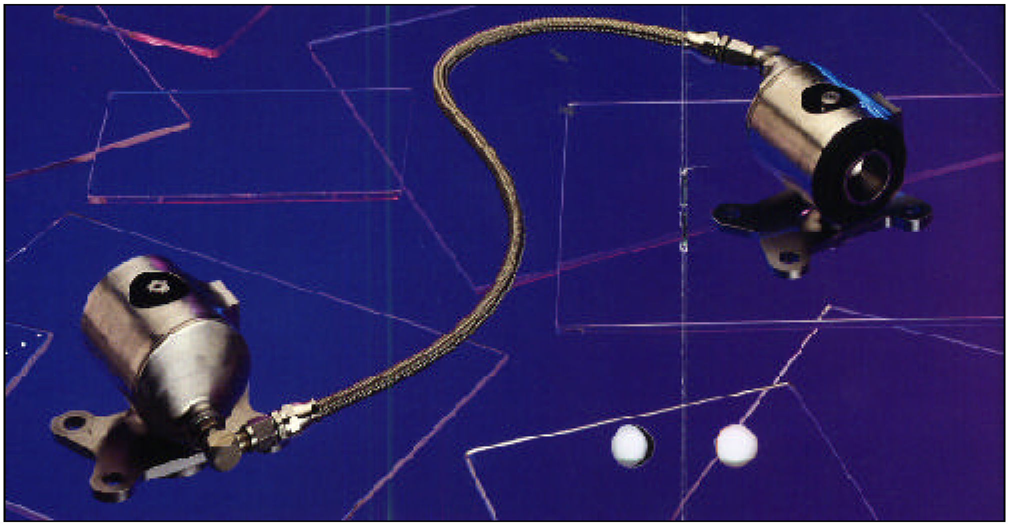


Figure 4.4 Typical Fluid Mounts With External Inertia Track [after 34]

The mount displacement passes the fluid from one cavity to another through the fluid (inertia) track. This phenomenon causes the rubber surrounding the fluid cavity to bulge. The combination of the fluid inertia and bulge stiffness of the rubber creates a tuned absorber effect that acts in parallel to the elastomer, as shown in Fig. 4.5. The tuned absorber effect is amplified by the leverage ratio between the piston area and the area of the inertia track, i.e.,

$$Leverage = \frac{A_{piston}}{A_{inertia\ \mathrm{track}}}$$

The piston area is defined as the effective cross-section of the cavity that the fluid presses against. The tuned absorber acting in parallel to the elastomeric mount creates a dynamic "notch" that causes a lower dynamic stiffness and, therefore, dynamic isolation. As shown in Fig. 4.6, the notch is placed within the operating range for the mount. This enables fluid mounts to be statically stiffer, for supporting load, and dynamically softer, for better isolation.

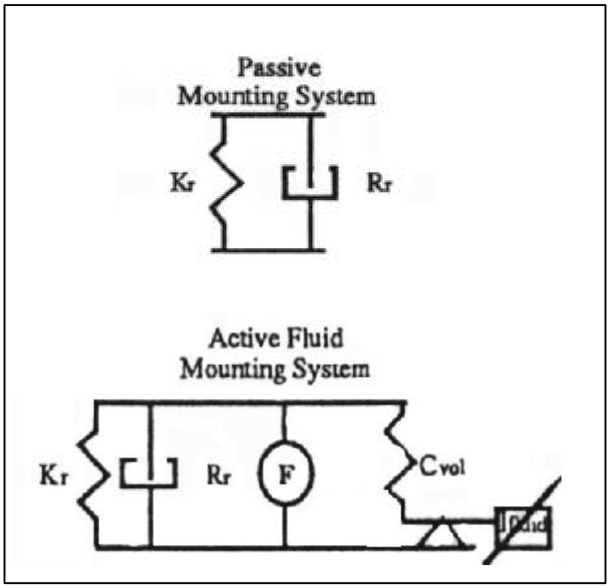


Figure 4.5 Schematic Comparison Between Fluid Mounts and Elastomeric Mounts [after 35]

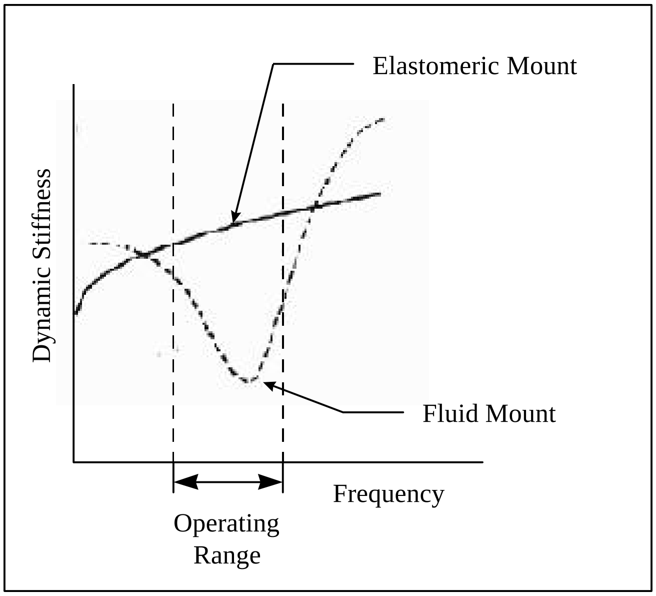


Figure 4.6 Isolation Advantage for Fluid Mounts

4.1.4 Active Mounts

As was mentioned in Section 1.2, active mounts have been evaluated in several past studies as more advanced alternatives to passive mounts for vibration reduction. Active mounts commonly augment the isolation effect of the passive mounts through the use of actuation elements. The actuation elements that have commonly been studied range from simple electromechanical actuators to piezoelectric elements to controllable fluids such as electro-rheological and magneto-rheological fluids.

In each case, the actuation mechanism serves two purposes:

1. it reduces the dynamic stiffness of the mount in the operating range, and
2. in most cases, it provides the ability to adapt to varying operating conditions, therefore optimizing the mount effectiveness under all conditions.

As shown in Fig. 4.7, the dynamic stiffness of the active mount has been lowered as compared to passive elastomeric and fluid mounts. Further, the notch frequency for the active mount can be adjusted to accommodate varying operating conditions.

It must be noted, however, that the application of active mounts involves costs and hardware complexities that do not suit many transportation applications. Here, this option was not consider because it falls outside the requirements by the railroad industry for a simple and rugged solution. Indeed, for this study, the simplest solution was chosen, namely elastomeric mounts.

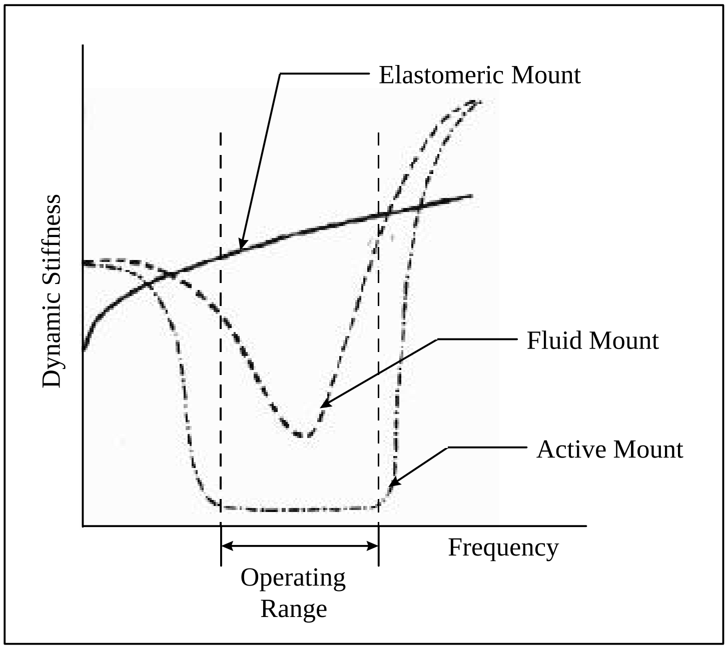


Figure 4.7 Dynamic Stiffness Comparison Between Active and Passive Mounts

4.2 Soft Mounts

To soft mount the cab, it must be completely disconnected from the sill structure and mounted on three or more resilient elements. The resilient elements that can be used for this purpose include

- rubber mounts
- metal springs
- air bags

The resilient elements must be capable of supporting the weight of the cab structure and providing isolation in the dynamic range of isolation. After considering all possibilities, elastomeric mounts were selected for this study. This selection was based on size, installation configuration, shear stability of the cab, and parts availability.

Elastomeric mounts proved to be the most compact, as compared to air bags and coil springs. Although it is possible to design air bags and coil springs that can provide the proper static support and dynamics isolation, they have a larger configuration than elastomeric mounts. This larger size presents problems in installation both for test purposes and actual manufacturing implementation. The installation problems include finding the physical space to accommodate the mounts, which raises the cab too high and, therefore, exceeds the height requirements of the locomotive.

Another problem with air bags and coil springs is shear stability. The resilient element is required to provide isolation in the vertical direction and yet have sufficient stability in the longitudinal and lateral directions (i.e., shear directions of the mount) so that the cab does not experience large displacement when it is subjected to lateral and longitudinal forces. Such forces can occur in coupling and uncoupling the locomotives to the train, or in curving. Air bags and coil springs have a minimal amount of shear stiffness and, therefore, are far less stable than elastomeric mounts in these directions. For elastomeric mounts, it is possible to adjust the shear stiffness properties of the mount through proper design of the mount dimensions, elastomeric compound, and shims.

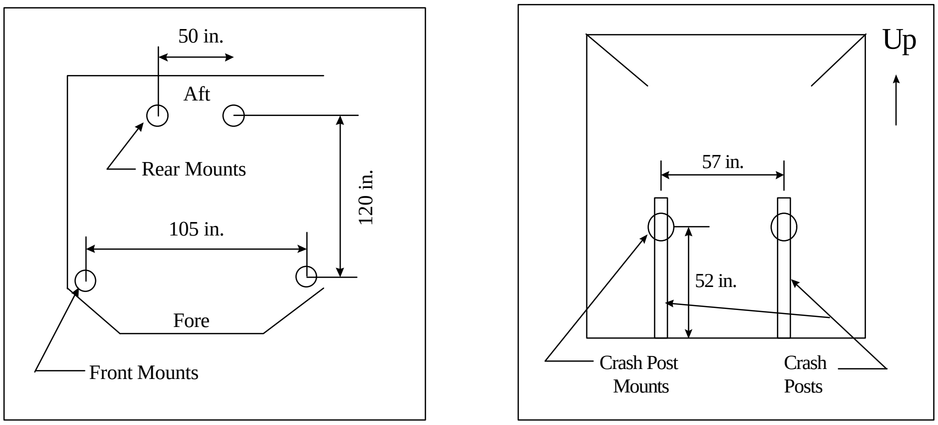
In terms of availability of parts for our testing, the elastomeric mounts were found to be the most favorable. Although a series of mounts were found in a Lord Corporation catalog to satisfy our needs, special coil springs and air bags were custom ordered at substantial cost. Therefore, two different series of mounts were chosen from Lord Corporation, Erie, PA, [32]. After working with Lord to determine the dynamic properties of the mounts in all 6 directions of motion, we selected the mounts in Table 4.1 along with the mount requirements in Table 4.2. Figure 4.8 illustrates the mount placement in the locomotive cab, while the base mounts and crash-post mounts are shown in Figs. 4.9 and 4.10, respectively.

Table 4.1 Mount Part Numbers and Locations

Part Number	Location
CB - 2205-3	Base Mounts
J-14056-4	Crash-Post Mounts

Table 4.2 Requirements for Soft Mounts from Lord Corporation

Requirements	X	Y	Z
Base Mount Stiffness (lb/in)	0.9600e4	0.9600e4	0.1670e5
Crash-Post Mount Stiffness (lb/in)	0.8500e3	0.8500e3	0.5100e4



(a) -(b)

Figure 4.8 Mount Configuration (a) Plan View (b) Front View

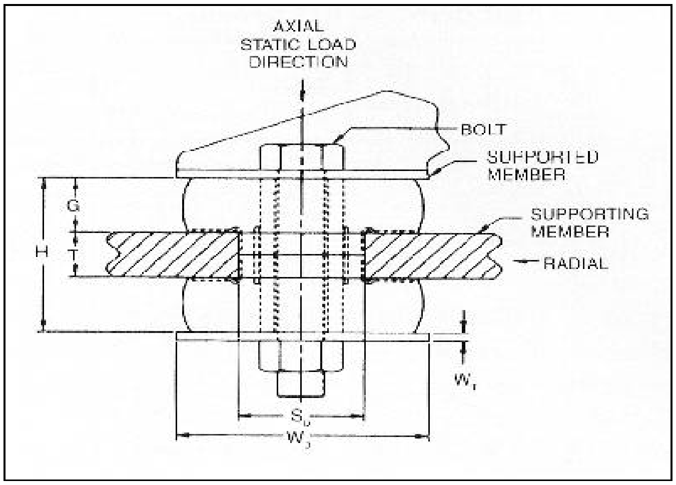


Figure 4.9 Base Mounts, Lord P/N CB-2205-3 [after 32]

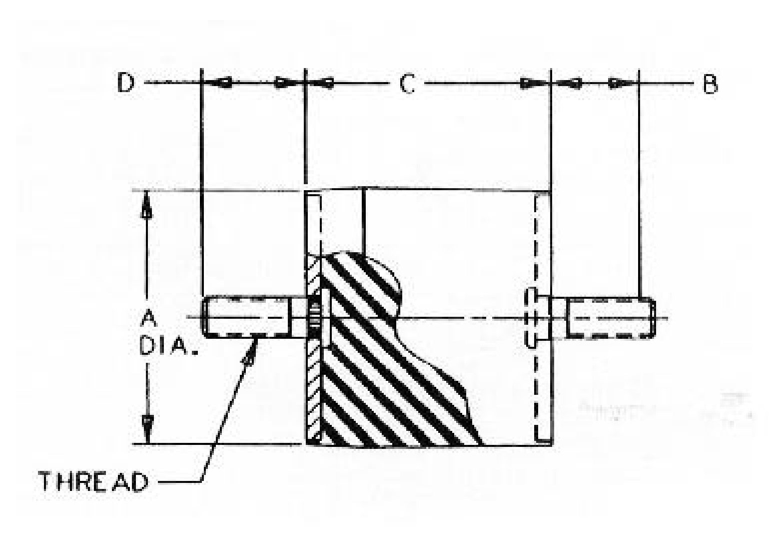


Figure 4.10 Crash-Post Mounts, Lord P/N J-14056-4 [after 32]

The crash-post mounts were installed to provide a higher stiffness in the longitudinal direction. The shear stiffness of the base-mount parts proved insufficient to prevent large displacement of the cab during coupling and uncoupling of the locomotive when the longitudinal forces are relatively large.

4.3 Soft-Mounted Configuration

In its original configuration, the locomotive cab is welded to the sill structure at the front and at four needle beams that are connected to the sill, as discussed in detail in this section.

To soft-mount the cab, it was cut from the sill structure along the welded joints. In Fig. 4.11, the joints burned off using an acetylene torch process are shown. The joints are marked in gray color. Not shown in the figure are the welded connections that were eliminated underneath the cab at the needle beams and along the crash posts in the front.

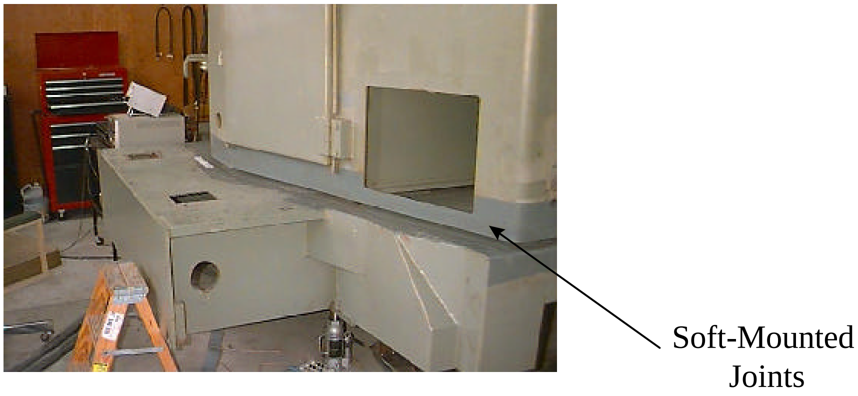


Figure 4.11 Welded Joints Eliminated for Soft-Mounting the Cab

Once the cab was completely separated from the sill, proper modifications were made to accommodate installing the elastomeric mounts at the four base locations and the two crash posts. As shown in Fig. 4.12, for the front base mounts, an L-shaped bracket was bolted to the cab on each side. The plate thickness for the bracket was selected such that it fit the requirement for the two-piece center-bonded mount that were selected for the base installation. Furthermore, the bracket was stiffened through gussets to reduce residual flexures at the bracket. The front mounts were bolted to the cab and sill structure, as shown in Fig 4.12.

As shown in Fig. 4.13, the modifications to the back of the cab were slightly more substantial. Since there was no structure adequate for installing the mounts, two thick plates were added to the cab structure. The 10.75 in x 8.0 in x 0.75 in plates were welded to the air brake cab structure such that they provide a sufficient support for the weight of the cab and adequate rigidity for soft mounting.

Two L-shaped brackets were added to each crash post for mounting the tube-form elastomeric mounts that were selected for these locations. As shown in Fig. 4.14, each bracket has a gusset to provide sufficient rigidity, as well as a slot that can easily accommodate the installation of the mounts. The brackets on the cab side were welded after the base mounts had been installed on the cab in order to properly align them to the brackets on the crash post. In a production environment, however, this can be done by properly incorporating the height adjustment into the installation at the crash-post mounts.

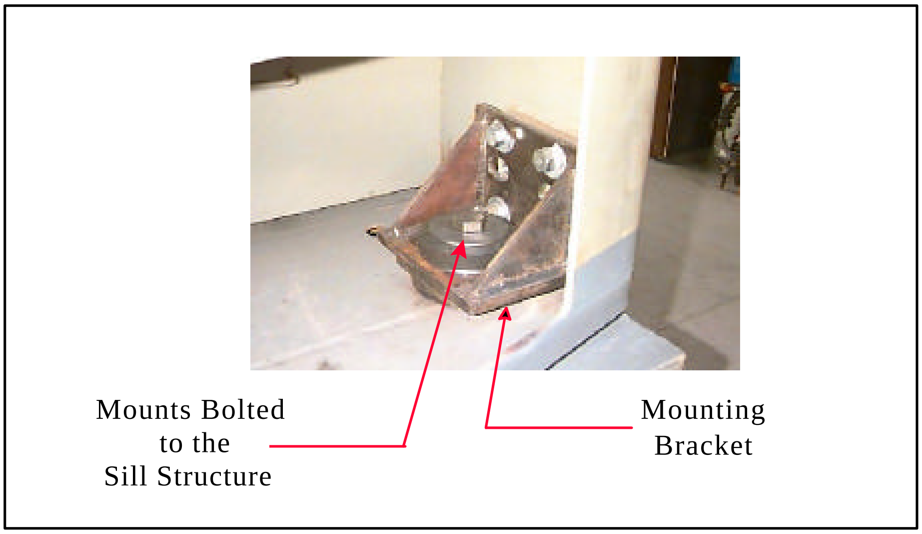


Figure 4.12 Front-Mounting Bracket Installation

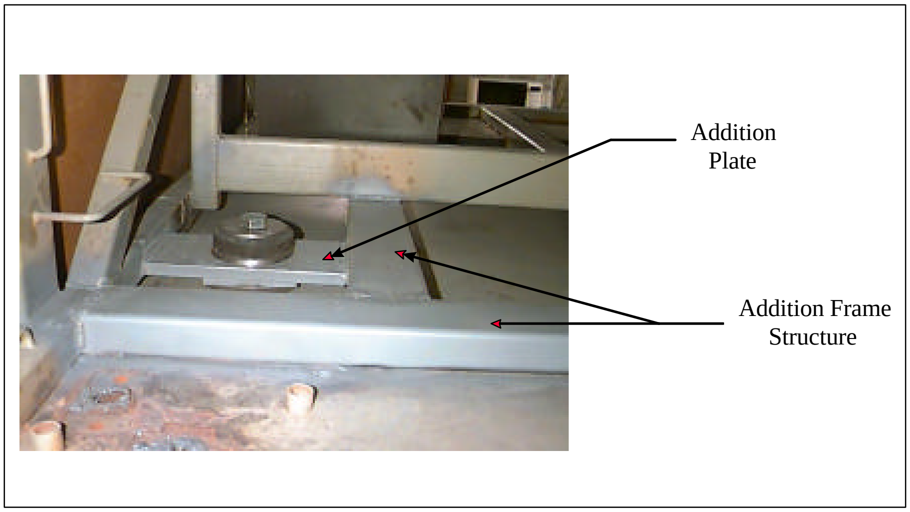


Figure 4.13 Modifications to the Cab for Installing Aft Base Mounts

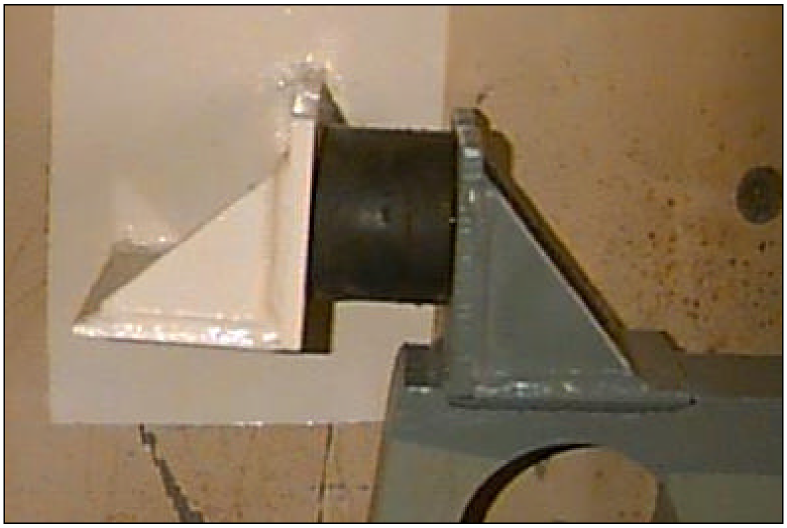


Figure 4.14 Crash Post Mount Brackets

The next step in soft-mounting the cab was to physically separate the cab and sill structure so that the mounts could be installed. The sill structure was lowered by deflating the air bags that support the cab. The cab structure was then jacked up with four 12-ton bottle jacks and supported on the four corners with stands. Stands were designed and built for this purpose. Figure 4.15 shows the stands used for supporting the cab.

This procedure provided us with sufficient room to install the mounts. Once the mounts were installed, the stands were removed and the air bags were inflated to their prescribed pressure. In this configuration, the separation between the cab and sill structure is only 0.875-in.

The last step in completing the soft-mounting of the cab involved installing the crash-post mounts. This included first welding the crash-post brackets at the proper height, and then bolting the mount in place. The cab-side bracket was then welded into place. The installation is shown in Fig. 4.14.

Figure 4.15 Stands for Supporting the Cab During the Installation of the Base Mounts

4.4 Soft-Mounted Cab Test Results

A series of tests were run on the soft-mounted cab to establish the benefits of soft-mounting in terms of reducing interior noise and vibrations. The tests for the soft-mounted cab are shown in Table 4.3, along with the tests conducted on the original cab.

In each case, the location of the accelerometers were kept the same as the original cab (discussed in detail in Section 3.3). The following provides an analysis of soft-mounted cab measurements and a comparison with similar measurements on the hard-mounted (original) cab.

4.4.1 Cab Floor Measurements

The measurements and coordinates for the cab floor are shown in Fig. 3.2 and Table 3.2. The accelerations at cab floor location 1, Fig. 4.16, show the following characteristics. The soft-mounted case shows that the vibration levels were minimized. The resonance peaks were eliminated across the spectrum especially at 120 and 160 Hz.

Table 4.3 Soft-Mounted Cab Tests

Vibration Testing	Baseline	Soft-Mounted
Floor	X	X
Roof	X	X
Nose Cab Floor	X	X
CA1 Doors	X	X
CA1 Outside		X
Consoles	X	X
LSI Cabinet		X
Sills		X
Nose Cab	X	
B-Side Outside		X

The accelerations at cab floor location 4, Fig. 4.17, show the following characteristics. The vibration levels in the hard-mounted case were higher than in location 1. Soft-mounting the cab virtually eliminating the vibration levels and resonance peaks. The major resonance peak at 50 Hz, which was one of the major problem areas, was nearly eliminated.

The accelerations at cab floor location 11, Fig. 4.18, show the following characteristics. The vibration levels were virtually eliminated, along with the resonance peak at 50 Hz. Soft-mounting was extremely successful at this point; Little additional improvement could be accomplished here.

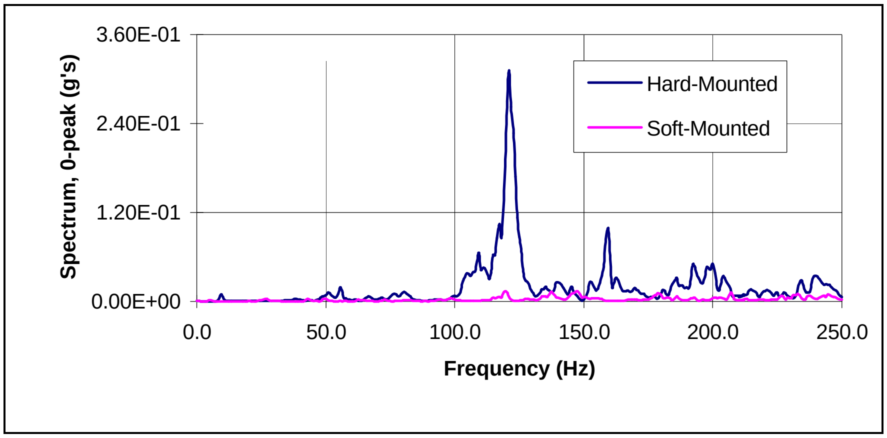


Figure 4.16 Accelerometer Cab Floor Location 1

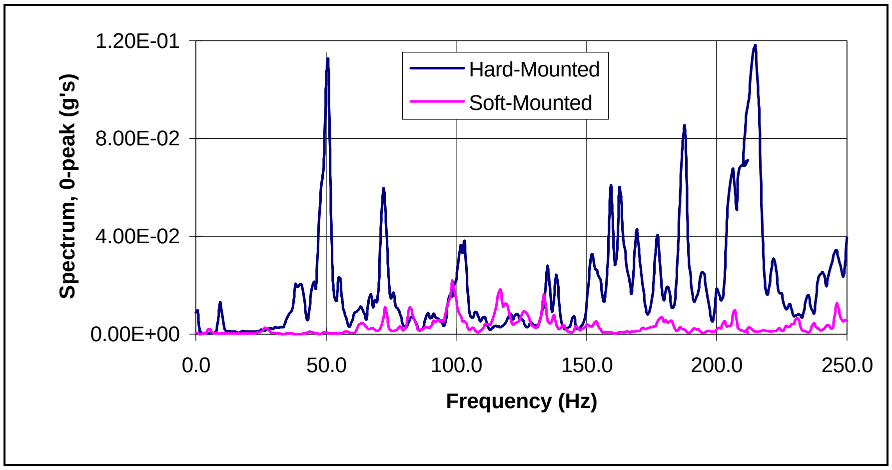


Figure 4.17 Accelerometer Cab Floor Location 4

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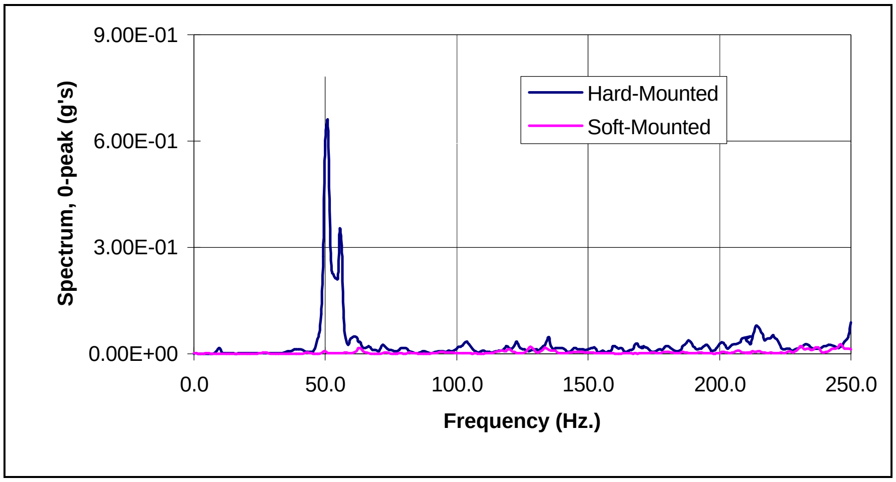

Figure 4.18 Accelerometer Cab Floor Location 11

Soft-mounting the cab eliminated the resonance peaks and lowered the vibration levels to virtually zero. The goal of eliminating the 50 Hz resonance peak was successful in the floor section of the cab. The next section will discuss the roof results after soft-mounting the cab.

4.4.2 Cab Roof Measurements

The measurements and coordinates evaluated for the cab roof are shown in Fig. 3.6 and Table 3.3. The plots compare the damped versus damped isolated case unlike, the plots in Section 3.3.2.

The accelerations at cab roof location 1, Fig. 4.19 show the following characteristics. The vibration levels were lowered considerably, and the resonance peaks were reduced, especially at 50 Hz. There were certain frequency ranges that were increased with the soft-mounted cab, as seen at approximately 45 and 65 Hz.

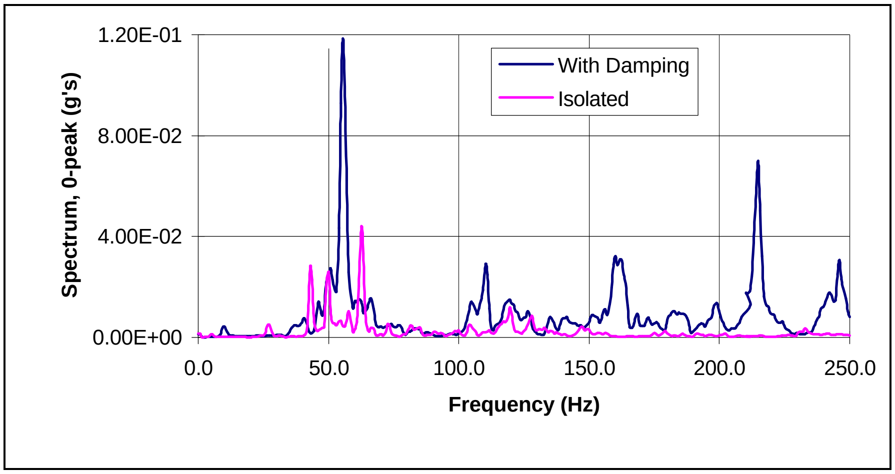

Figure 4.19 Accelerometer Cab Roof Location 1

The accelerations at cab roof location 8, Fig. 4.20, show the following characteristics. The effects of the soft-mounted case include a large reduction in vibration levels. The resonance peak at 50 Hz was increased, which was not beneficial. The peak of the hard-mounted case at approximately 65 Hz shows the effect of the soft-mounted cab; the frequency of this peak was shifted to the left or downward as expected. The shift in frequency is characteristic of the soft mounts.

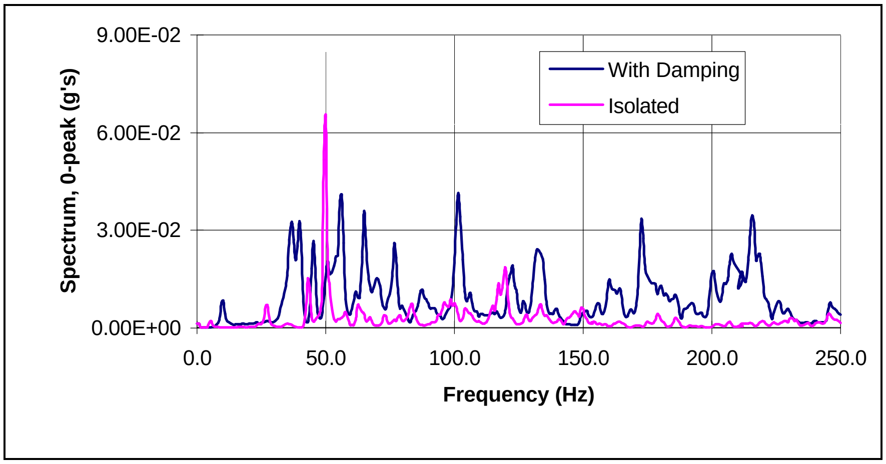

Figure 4.20 Accelerometer Cab Roof Location 8

The reduction in vibration levels was significant in the roof section of the cab. There were a few increases in vibration levels, but the overall reduction overshadowed the increases. The overall reduction in vibration helped to reduce the sound pressure level.

4.4.3 Nose Cab Floor Measurements

The measurements and coordinates evaluated for the nose cab floor are shown in Fig. 3.9 and Table 3.4. The nose cab floor was modified for the soft-mounted configuration. A raised sub-floor was added to eliminate noise transmission up through the floor.

The accelerations at nose cab floor location 1, Fig. 4.21, show the following characteristics. The vibration levels were reduced considerably. This is mainly due to the fact that the mounts restrict the energy from entering the cab and the floor is not being attached to the sill plate, as with the original cab configuration. The resonance peaks at 40, 50, 60, and 135 were eliminated, along with the smaller insignificant peaks.

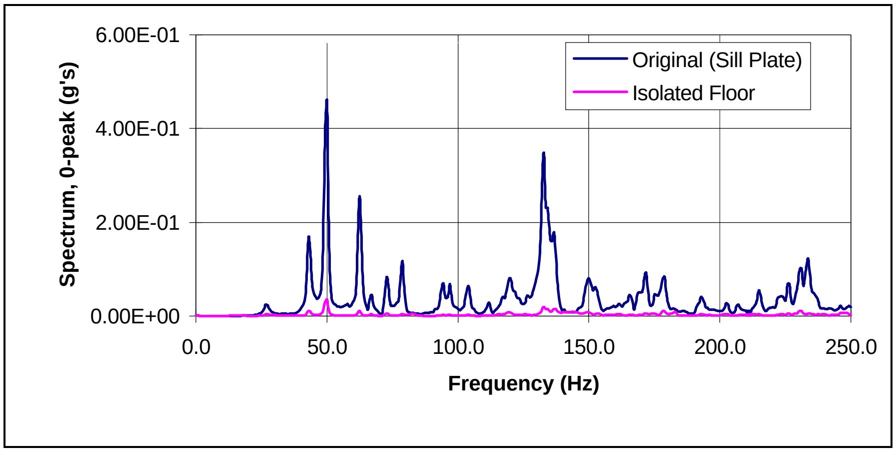

Figure 4.21 Accelerometer Nose Cab Floor Location 1

The accelerations at nose cab floor location 2, Fig. 4.22, show the following characteristics. Soft-mounting reduced all the vibration levels across the spectrum. All the resonance peaks were lowered to relatively zero. As stated above, the floor is a raised platform and contributes to the reduction in vibration level along with the soft-mounting of the cab.

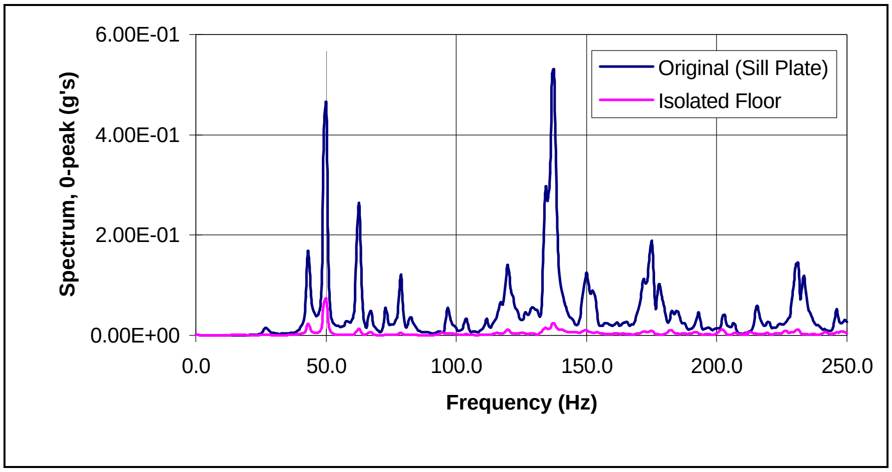

Figure 4.22 Accelerometer Nose Cab Floor Location 2

The soft-mounted cab along with the raised floor gave the largest benefit in this area; there are minimal improvements that could be made in this area.

4.4.4 CA1 Doors, Consoles, and LSI Measurements

The accelerometer locations made on the CA1 cabinet interior surface are shown in Fig. 3.12, and the coordinates are shown in Table 3.5. The accelerometer locations are not shown for the consoles and LSI cabinet.

The accelerations at CA1 cabinet location 1, Fig. 4.23, show the following characteristics. The peaks at 205 Hz were eliminated, and the peak at 50 and or 80 Hz was shifted to approximately 70 Hz, with a decrease in amplitude. The remainder of the spectrum was decreased to relatively zero.

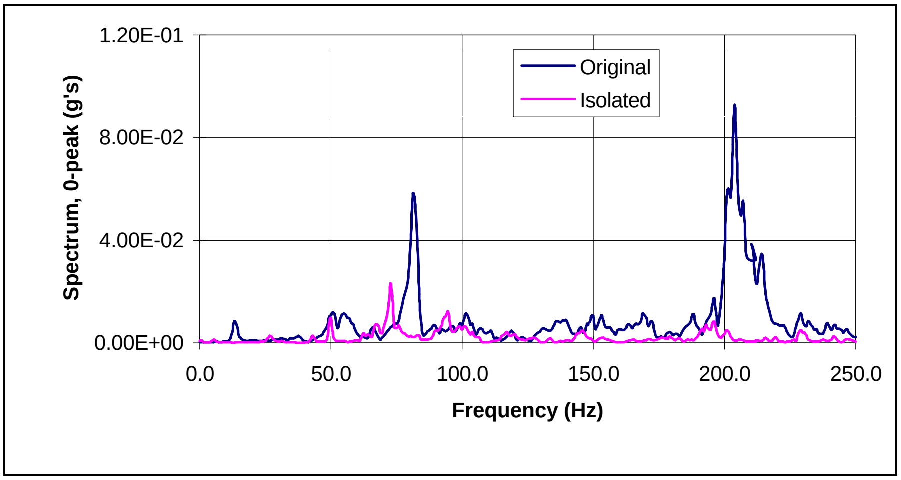

Figure 4.23 Accelerometer CA1 Cabinet Location 1

The accelerations at CA1 cabinet floor location 4, Fig. 4.24, show the following characteristics. The vibration levels were reduced across the spectrum. The resonance peak at 50 Hz was increased along with the peak at 90 Hz. The peak at 90 Hz was increased, due to the shift in frequency from the soft-mounting of the cab. The shift was caused by the mount characteristics. The vibration levels were reduced by as much as 4 times the original values.

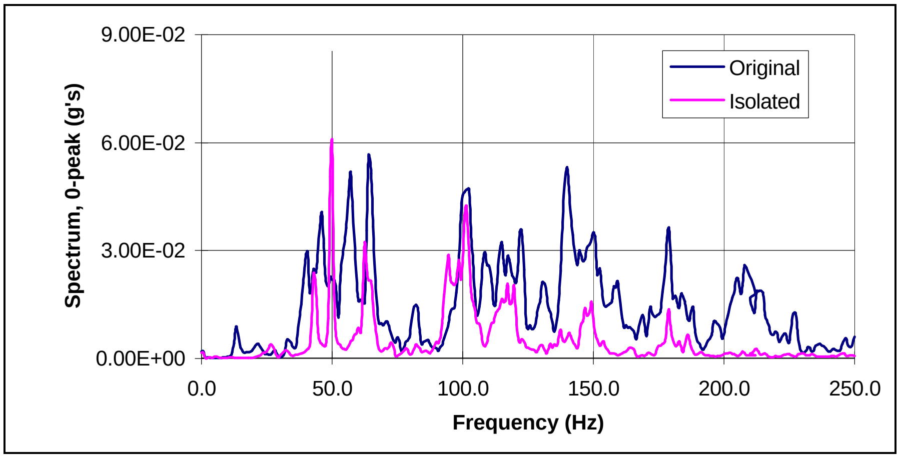

Figure 4.24 Accelerometer CA1 Cabinet Floor Location 4

The accelerations at engineer's console location 10, Fig. 4.25, show the following characteristics. The vibration levels were reduced to relatively zero. The high frequency vibrations were affected the greatest. The two resonance peaks at 12 and 50 Hz were eliminated, which eliminated the resonance at the engineer's console.

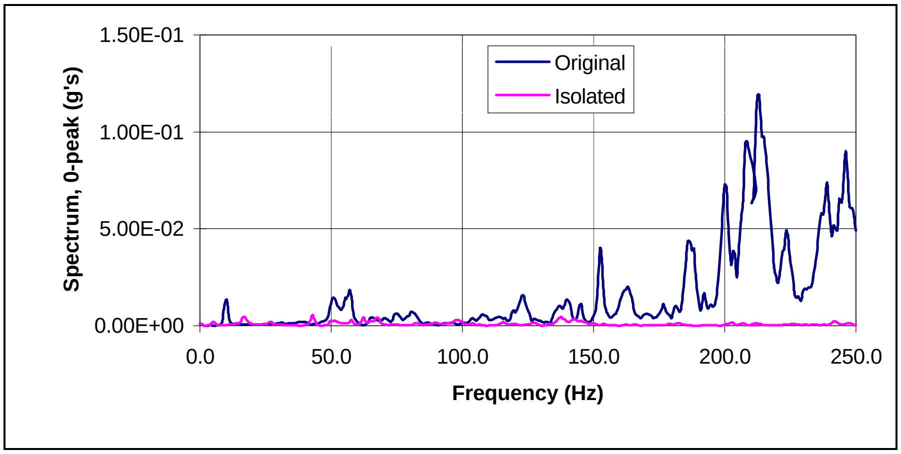

Figure 4.25 Accelerometer Engineer's Console Location 10

The accelerations at conductor's console location 6, Fig. 4.26, show the following characteristics. The peaks at 12 and 50 Hz were eliminated at the conductor's console. The consoles originally resonated at the 12 Hz frequency. This was eliminated with the soft-mounted structure. A major resonance peak was eliminate in the 220 Hz range. There were a couple of peaks that were increase such as 75, 95, and 140 Hz.

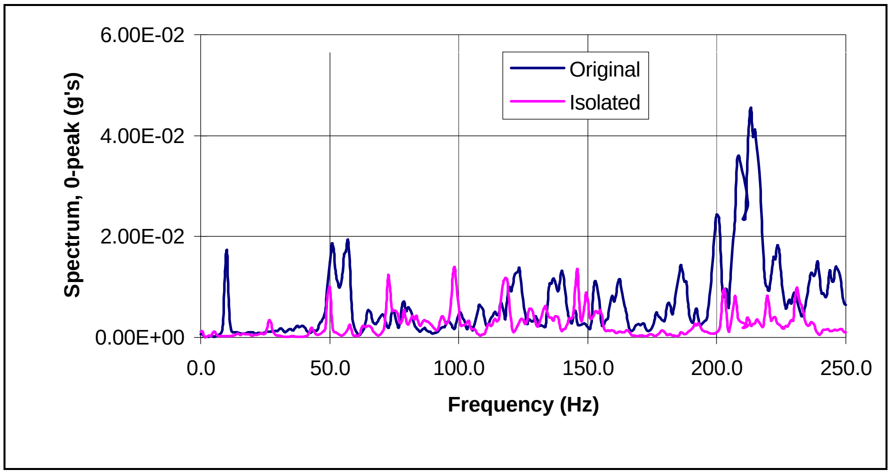

Figure 4.26 Accelerometer Conductor's Console Location 6

The accelerations at LSI cabinet location 11, Fig. 4.27, show the following characteristics. The LSI cabinet produced the same results as the other sections of the cab. The vibration levels were considerably reduced; the resonance peak at 125 Hz was increased, but the peak at 50 Hz along with the resonance peaks at 135 and 230 were all eliminated.

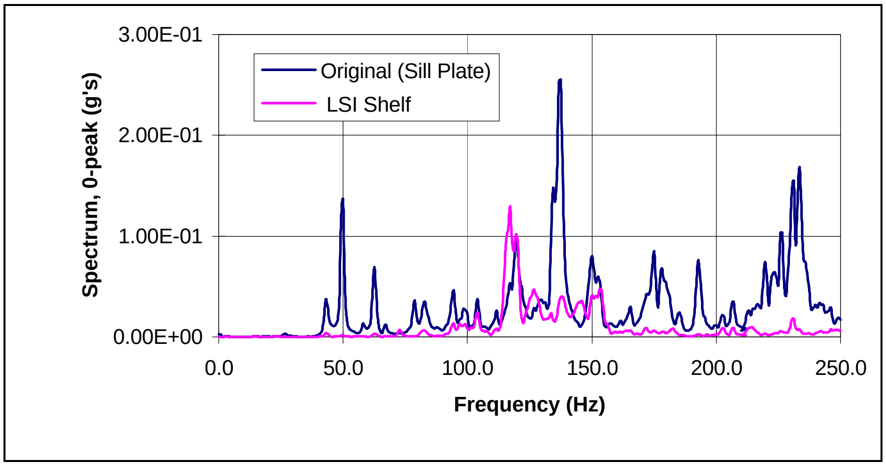

Figure 4.27 Accelerometer LSI Cabinet Location 4

The soft-mounting of the cab resulted in a decrease of vibrations in all sections of the locomotive cab. The contributions to the decrease in the overall interior noise levels of the cab were substantial; the interior noise level was reduced by approximately 6 dBA compared to the baseline cab. The quality of the noise level was improved over the stiffening of the floor. Additional plots are shown below indicating the different locations presented above.

The following is an example of the acceleration levels on the outside of the CA1 cabinet as shown in Fig.4.28. This portion of the cab did not have a baseline test, so it will be compared to the stiffened floor test. The results are similar to the other sections of the cab. The resonance peaks at 12, 50, and 195 Hz were all eliminated, while the other resonance levels were reduced to insignificant levels. The peak at 120 Hz was increased due to the soft mounted cab configuration. This will improve electronic life along with sound pressure-level reduction.

The plot in Fig. 4.29 compares the accelerations on either side of the soft-mount. This shows that the mount reduces high frequency vibrations. The vibration levels above 150 Hz were reduced considerably. The low frequency vibrations were also reduced and even eliminated in certain frequency ranges. This shows that the transmission of vibrations through the soft-mount is minimal, and the mount is very successful for the purpose intended.

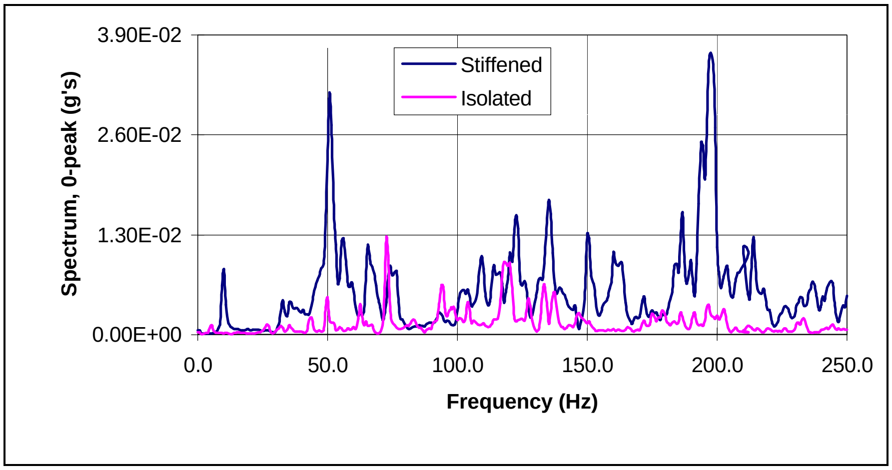

Figure 4.28 Accelerometer CA1 Cabinet Outside

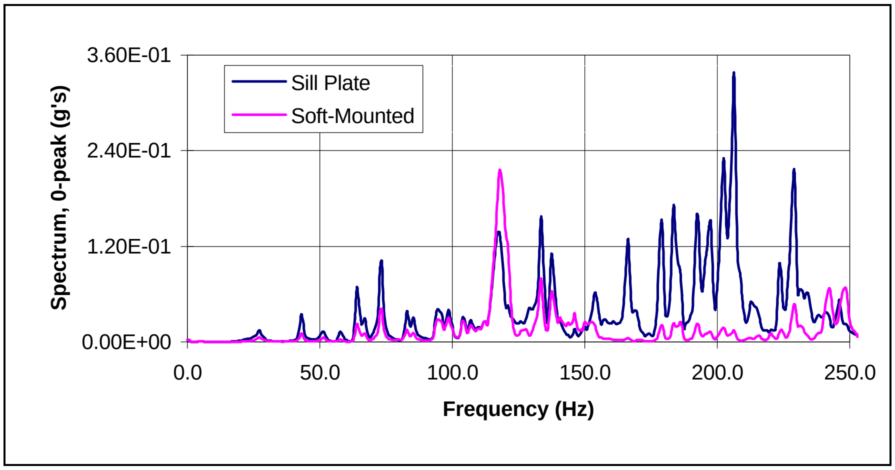

Figure 4.29 Accelerometer B-Side Mount

The soft-mounted cab proved to be beneficial to reducing the noise levels and vibration levels. The soft-mounts have reduced the number of points where the energy can enter the cab. For this reason, the vibration levels have decreased throughout all sections of the cab. Since the vibration levels have reduced, the noise levels are lower because the panels are not flexing, causing the sound pressure waves in the cab.