Report on Vibratory Stress Relief

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At the direction of NEW YORK STATE DEPARTMENT OF TRANSPORTATION (NYDOT), HARRIS STRUCTURAL STEEL undertook a heat-straightening of a 60'L, 86,500 pound bridge segment, which resulted in unacceptable distortion. The addition of internal bracing near each end of the segment resolved the distortion, however NYDOT required that a stress relief be done, to ensure structural integrity. The most practical means of doing so was the VSR Process.

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HARRIS STRUCTURAL STEEL utilized heat-straightening on a bridge segment, which resulted in some unacceptable distortion. The addition of internal bracing near each end of the segment resolved the distortion, however NYDOT required that the piece be stress relieved, to ensure structural integrity in the aftermath of heat-straightening, and the welding needed to install additional internal braces near each end.

The bridge segment weighed 86,500 pounds, and measured 40" x 98" x 60'. Most of the plate-work was ¾" - 1" thick, and made of ASTM 710, Grade 50 low-carbon, high-strength steel.

This ASTM 710 material is categorized as "at risk for suffering degradation of its physical properties – specifically loss of strength and toughness – if subjected to thermal stress relief". See *Thermal Stress Relief: Risk for Low-Carbon, High-Strength Steel Alloys,* which is appended to this Report.

VSR Setup
The workpiece was placed on four (4) Isolation Load Cushions. These Cushions were placed on each side of the piece, on top of steel structural supports, 18' from each end of the workpiece. This arrangement minimizes vibration damping of long, beam-shaped structures. (See VSR Report on Ingersoll 59 Footer, http://www.vsrtechnology.net/pdf/Ingersoll_59L_Gantry_Report.pdf). Minimizing the damping enables maximum workpiece resonance during VSR Treatment.

Several independent research works, including those of Hahn[1], Shankar[2], and Yang, Jung and Yancey[3], have proven that resonance frequency vibration is the most effective form of vibration to relieve stress.

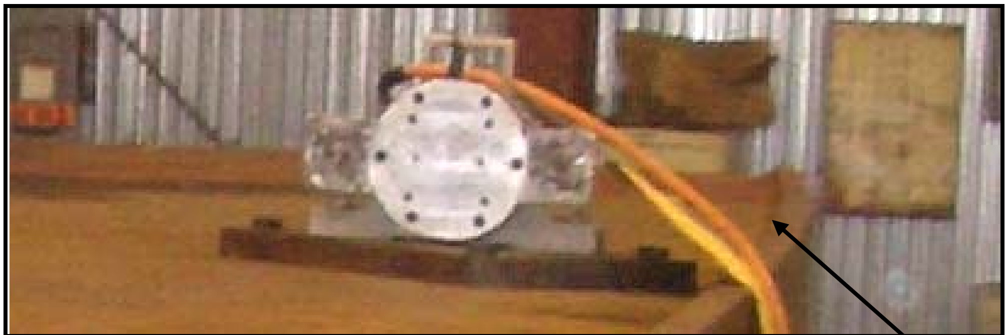
Strong, rigid structures, eg, this bridge member, have very narrow resonant peaks, which require tightly-controlled vibration frequency to achieve full resonant response during VSR Treatment. The VSR-8000 System offers speed control of ± 0.03% of full range, so that such strict resonance requirements can be achieved.

The Accelerometer, a vibration sensor whose output is proportional to acceleration, was clamped on a corner of the workpiece, and oriented so to be most sensitive to signal generated from vertical amplitude. Acceleration has been shown to be the best parameter to gauge vibration intensity, due to its proportionality to force, based upon Newton's Second Law: **F = ma** . . . where **F** is force, **m** is mass, and **a** is acceleration.

The Vibrator was positioned 30% from the end (from the far end in the photos). It was clamped in place using a 2" thick adaptor plate that mated with the existing bolt patterns in the workpiece and Vibrator. A drawing of the plate is shown at the end of this Report.

[1] Dr. William Hahn, Vibratory Residual Stress Relief and Modifications in Materials to Conserve Resources and Prevent Pollution
[2] Dr, S, Shankar, Vibratory Stress Relief of Mild Steel Weldments
[3] Drs. Y. P. Yang, G. Jung, and R. Yancey, Finite Element Modeling Of Vibration Stress Relief After Welding
Note: All three papers can be found at http://www.vsrtechnology.net/library-articles.html

The Vibrator not only has adjustable speed, ranging from 10 thru 8000 RPM, but also adjustable unbalance, from 0.2 thru 4.0 in-lbs. This allows both a wide range of workpieces to be treatable using the VSR Process, and different unbalance settings to be used on the same workpiece, (settings selected for different RPM ranges, based upon the response of the part). This capability allows VSR Treatment that is either global, or focused upon portions of a workpiece.



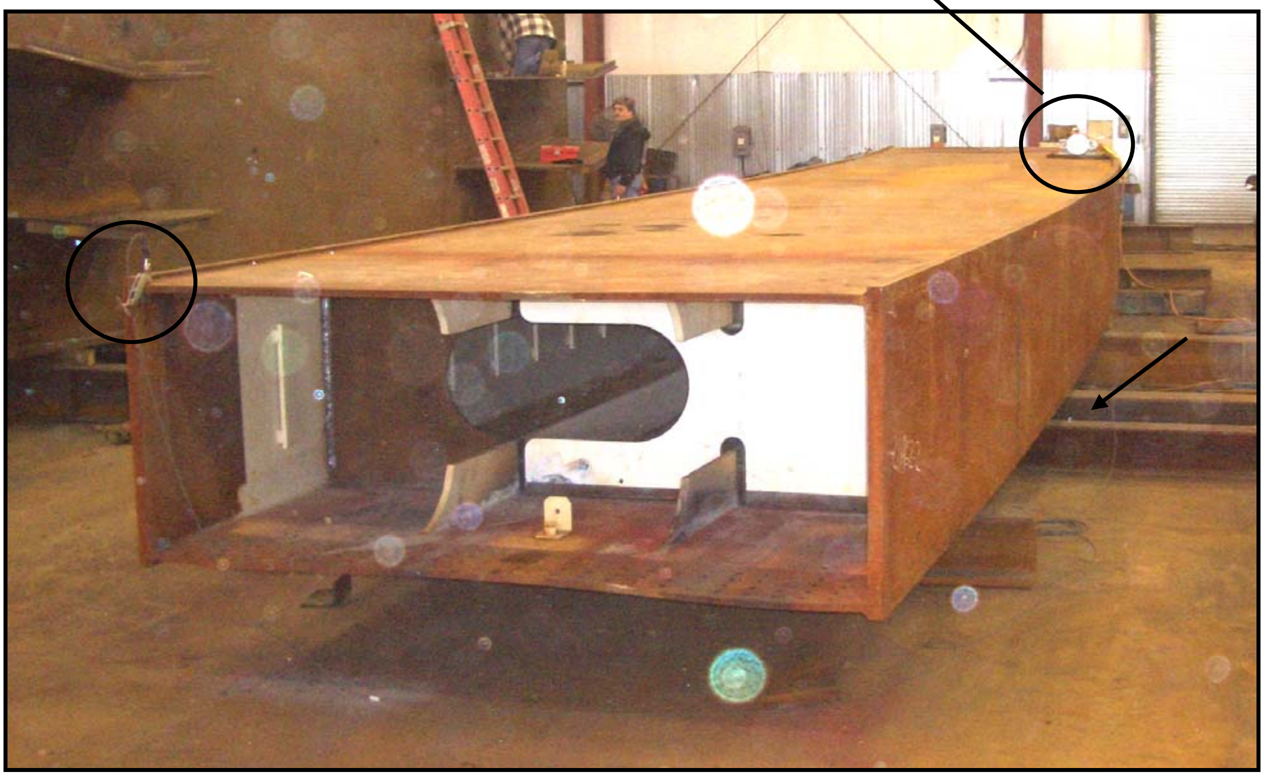


Figure 1: 60' L bridge arch segment, setup for VSR Treatment. Areas of concern were near each end, where both welding HAZ's (Heat Affected Zones) associated with the internal bracing (white-painted plate in foreground), and nearby areas that had received heat-straightening efforts were situated.

Four (4) Isolation Load Cushions were placed between width-wise beams, on each side, 30% (≈ 18') from the ends (see arrow above). This minimizes damping, and thus, maximizes "resonate-ability".

A clamp-mounted Accelerometer, visible in the left foreground (circled), feeds vibration data to the VSR-8000 Control Console.

The Vibrator is mounted 70% down the length of the right side of the workpiece, on top (circled). The Vibrator's AOR (Axis of Rotation), was aligned with the length of the workpiece, an orientation which generates the greatest number of resonant peaks.

Figure 2: System's MX-8000 Control Console, featuring an industrially-hardened 15" touchscreen PC, and a brushless DC drive. The keyboard allows saving/labeling of VSR Treatment Chart data shown in Figures 3 - 6. This Console can control the Vibrator RPM very precisely, regulation being ± 0.03% typical, in fine-tuning increments of 1-RPM. With the resonant peaks being narrow, this precision was required to effectively stress relief a heavy, rigid structure, such as the subject workpiece. The Console operates on 200 – 240 VAC single phase, with 20 amp max requirement. Two (2) fully-active USB jacks on the Console panel, to the left of the PC, allow connection of keyboard, mouse, printer, network black-box, etc. This console is available in UL, CE, or JIC standard versions. The enclosure meets NEMA 4 / IP 65 ingress standards.

VSR Treatment

After the setup (placement of the workpiece on the Load Cushions, and attachment of the Vibrator and Accelerometer), preliminary or Quick Scans were done to gauge the response of the workpiece to vibration. Quick Scans verify that resonance is being achieved, and gauge how strong and at what frequency range they occur. Adjustments to the Vibrator's unbalance, the RPM range, and, if needed, the location and orientation of the Vibrator and Accelerometer are made, so as to generate VSR Charts that show resonance activity.

VSR Charts display two curves: An upper curve, in which the vertical axis is workpiece acceleration (g), and a lower curve, in which the vertical axis is Vibrator Power (watts or % of max power). Both are plotted against the horizontal axis which is Vibrator Speed (RPM).

Peaks in the upper curve are resonances of the workpiece. Peaks in the lower curve are also a resonance of the workpiece, but one that causes additional amplitude of the Vibrator. By adjusting the unbalance of the Vibrator, or shifting the location of the Vibrator, or a combination of both, excessive high peaks in the power curve can be controlled, so as to remain well within the power range of the Vibrator.

The System's BL8 Vibrator is driven by a 3 HP (≈ 2.2 kW) brushless DC motor. This provides 3 – 6 times the "headroom" (space between normal operating levels and motor capacity), that other vibratory stress relief vibrators provide. It also has a broader RPM range, from 10 – 8000 RPM. This Vibrator also has continuously variable unbalance, from 0.2 thru 4.0 in-lbs. At maximum speed and unbalance (a setting rarely needed to perform the VSR Treatment), the Vibrator has a force output of more than 7,000 lbs.

A Pre-Treatment Scan, showing the first set of data used to perform the stress relief treatment on the workpiece, is shown in Figure 3.

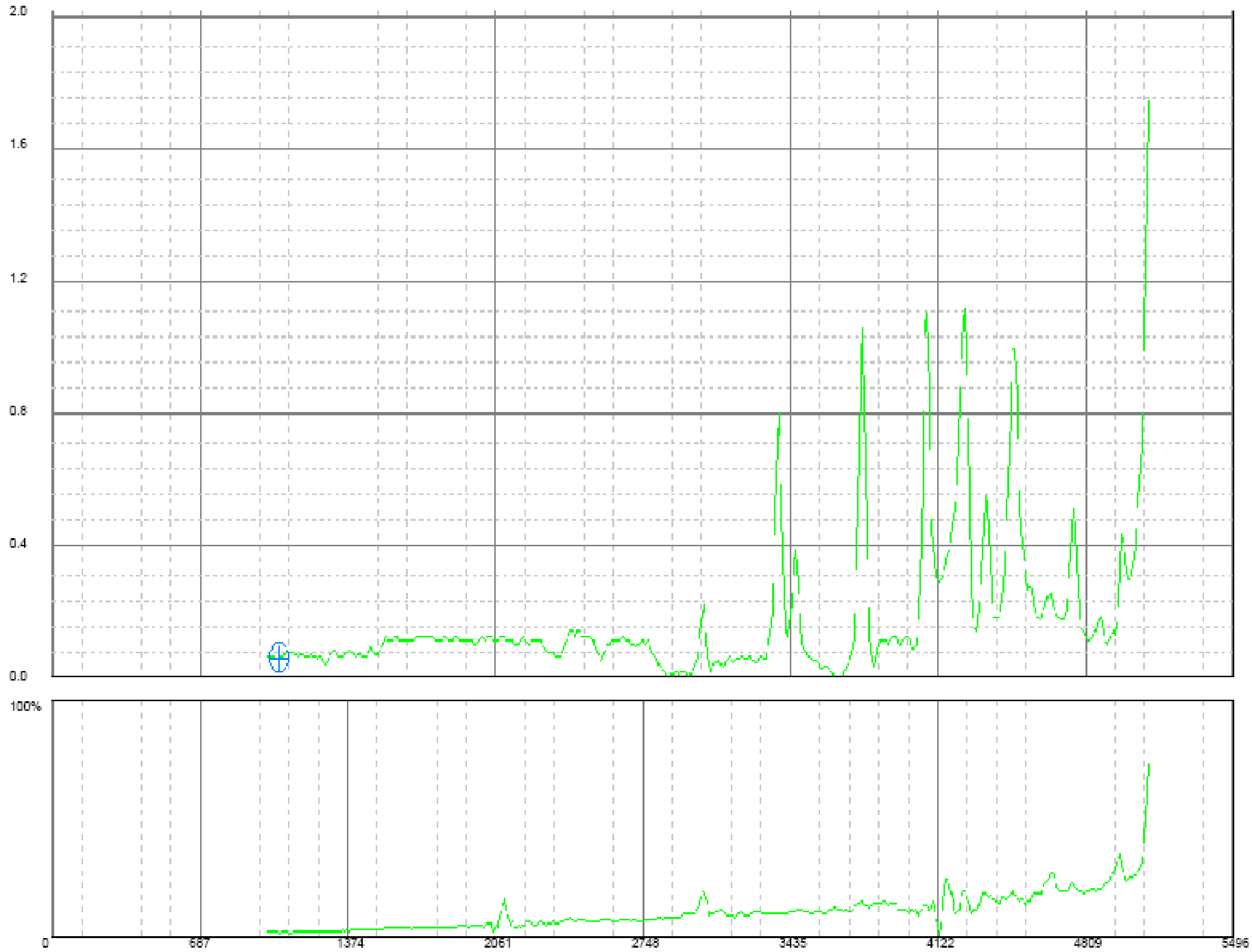


Figure 3: First Pre-Treatment Scan. This scan showing a high power condition near the end of the scan (≈ 5 kRPM) was made with an unbalance setting of 30% (1.2 in-lbs.). Blue cursor at the beginning of acceleration (acc) curve is the real-time indicator of Acc and RPM. Pre-Treatment Scan data is recorded in green, since the workpiece is green, ie, not stress relieved, like a green casting.

VSR Treatment is done by tuning upon and then dwelling on the resonance peaks. This was done by using the MX-8000 Console's Vibrator speed controls, which can tune the vibrator speed in increments of 1-RPM, to tune directly upon the each of the resonance peaks. If stress relief is occurring, the workpiece will become more limber or less rigid, which causes the resonance peaks to both become higher in amplitude (the major response), and to shift most often in the direction of lower frequency

(to the left). This did occur, but only to a nominal degree. After the mild change that did occur in the resonance pattern, a Post-Treatment Scan (recorded in red) was done,, and superimposed on the Pre-Treatment Scan, shown in Figure 4.

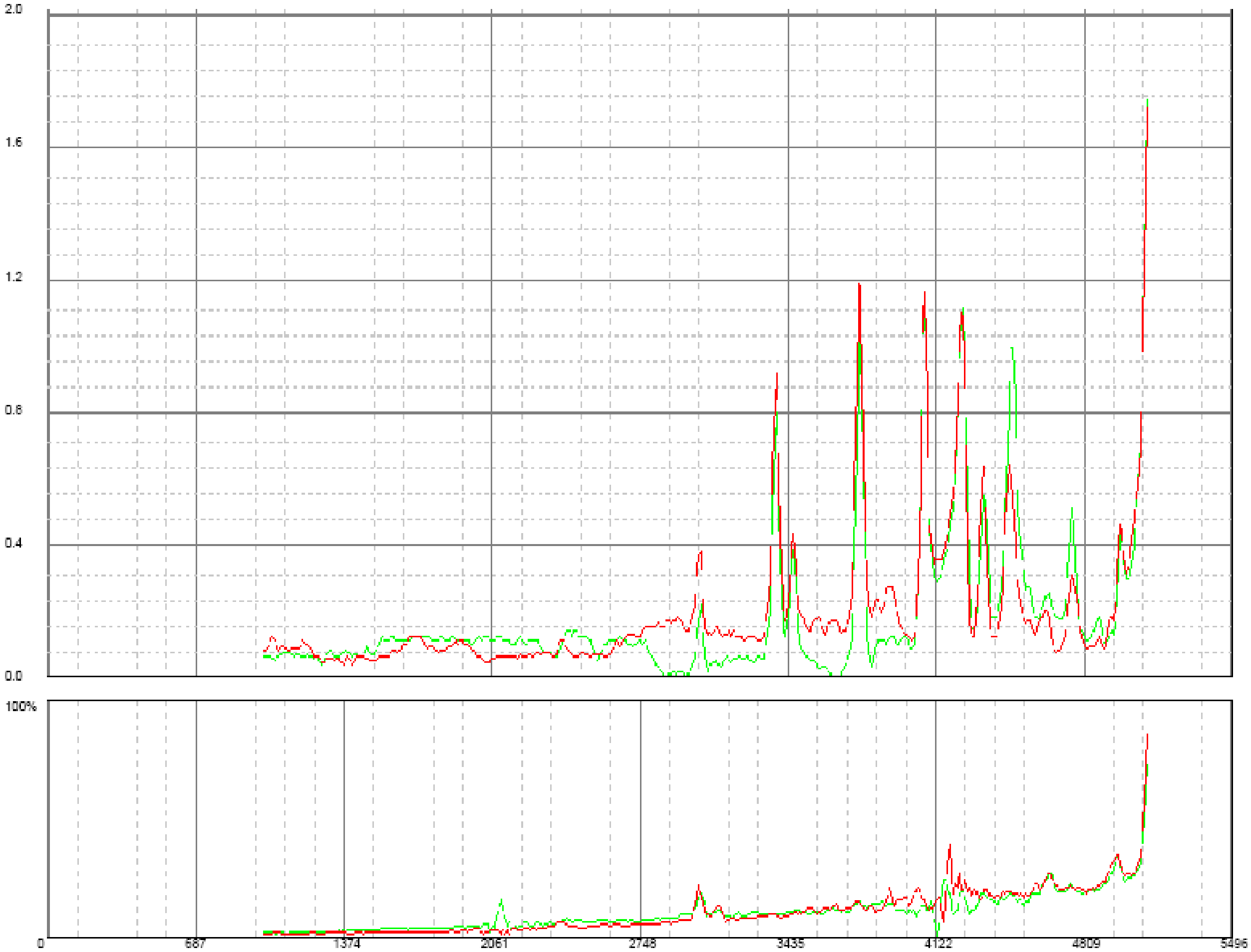


Figure 4: 1st VSR Treatment, 30% unbalance, 5.5 kRPM max speed. Mild response.

A second VSR Treatment was done, but with two modifications: A decrease of the unbalance from 30% to 15% (from 1.2 to 0.6 in-lbs), and an increase of the max RPM to 6000 RPM. This allowed the resonance at ≈ 5 kRPM to be achieved, without excessive peaking of the vibrator input power. Although some peaks that were near the top end of the Vibrator capacity did occur, we were able to achieve 6000 RPM (a peak in power in excess of 2.2 kW will trigger the MX-8000's motor protection circuitry).

This Treatment provided a greater response than the first Treatment, especially the growth of the peak ≈ 5 kRPM, which grew by approximately 40%, from 1.36g to 1.92g., as shown in Figure 5.

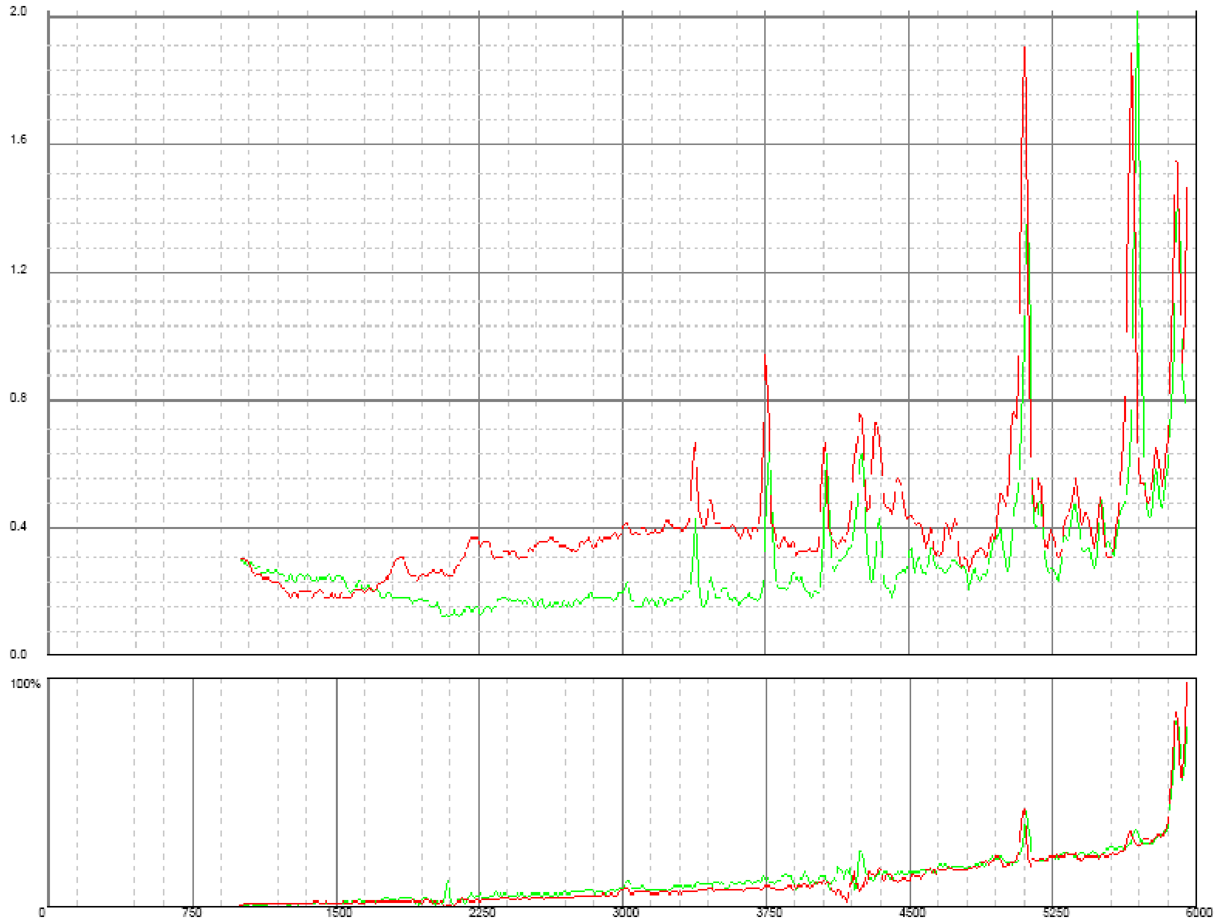


Figure 5: 2nd VSR Treatment, 15% unbalance, max RPM = 6000. Largest change in response pattern occurred at ≈ 5 kRPM, peak growth being ≈ 40%. Note the power peak associated with this resonance peak, which now is smaller compared with the 1st Treatment, where it caused the power protection to trip. Raising of the "valley" in the lower RPM range also occurred.

A third VSR Treatment was also done, this time limiting the Vibrator RPM to 4500, but setting the unbalance at maximum: 100% or 4.0 in-lbs. This resulted in a Treatment that showed relatively little change in the resonance pattern, as shown in Figure 6.

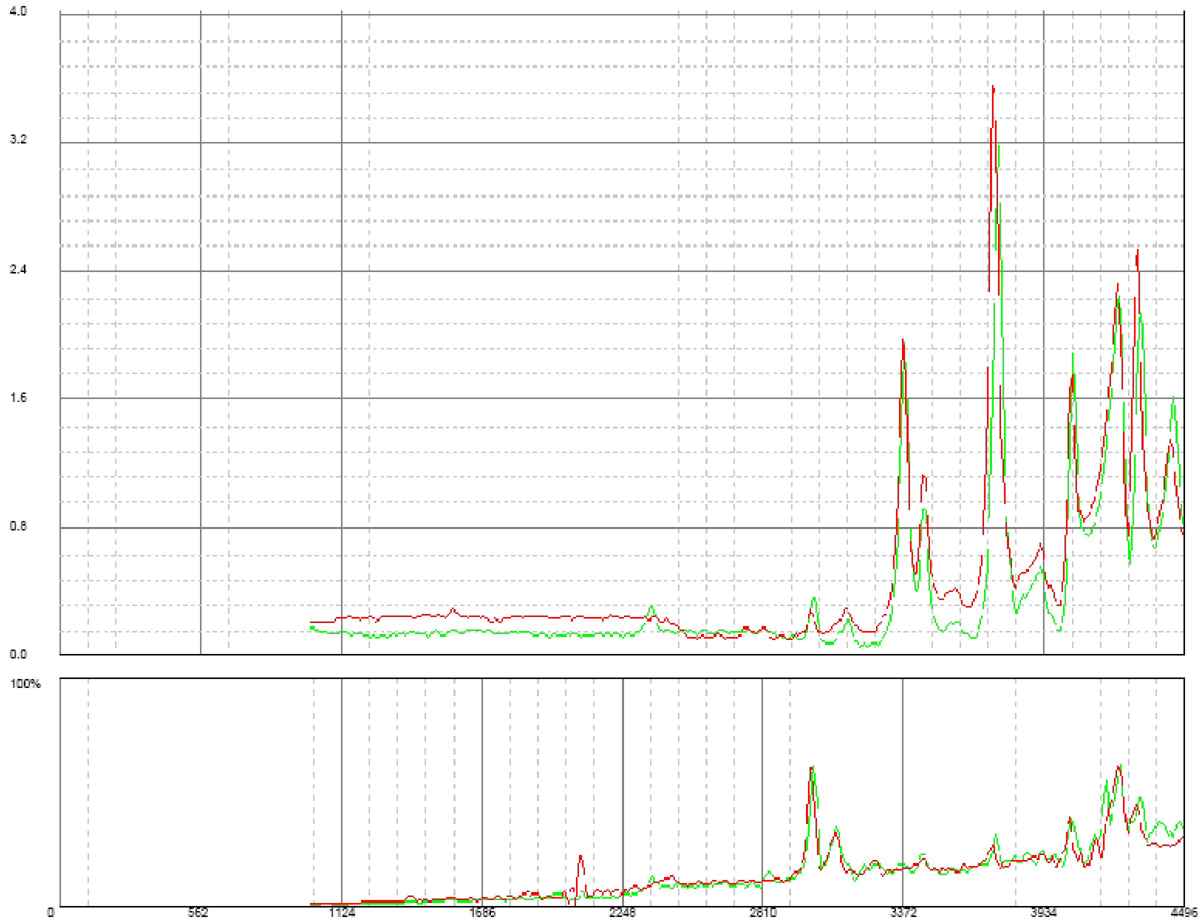


Figure 6: Max unbalance (4.0 in-lbs), max RPM = 4500. This VSR Treatment shows a relatively stable resonance pattern.

Discussion

Generally speaking, and certainly in the case of long, box-beam configurations, the lowest resonances are the fundamental frequencies of a workpiece, and cause amplitude to occur globally within the workpiece. As higher frequencies are achieved, the tendency is for the area being flexed to become more local in nature.

The residual stress pattern that this workpiece had was not global in nature, since most of the welding was not fresh, ie, recently done. Rather, two portions of the workpiece, one at each end, had undergone heat-straightening. These areas also were nearby the location of the additional brackets and their welding.

The stresses associated with these areas did not affect the resonance pattern of the workpiece at low frequencies, but did so for higher frequencies, that have more local generation of flexure.

Conclusion

The VSR Treatments detailed in this Report indicate that this structure should exhibit good dimensional stability during subsequent transport, erection and usage. After VSR Treatment, the bridge span was carefully visually examined and found to be dimensionally accurate, and within a week was transported to the installation site, near Buffalo, NY.

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4 March 2007

THERMAL STRESS RELIEF:

RISK FOR HIGH-STRENGTH, LO-CARBON STEEL ALLOYS

The use of high-strength, lo-carbon steel alloys is increasing. Often this is due to upgraded design requirements on new projects and products, or efforts to upgrade or improve the performance of existing products. Application areas for these steels include, but are not limited to, pumps, mining and construction equipment, and bridge components.

Unfortunately, many of these grades of steel suffer negative side effects, when thermally stress relieved.
The negative side effects are listed in the Plate Steel Specification Guide of MITTAL STEEL which can be seen at:
http://www.mittalsteel.com/documents/en/Inlandflats/ProductSpecification/MITTAL%20SPEC.%20GUIDE.PDF

These negative side effects fall into three (3) basic Categories (Cat), although Cat 2 has a subset, Cat 2A, and Cat 3 is a variation of Cat 1. For purposes of this document, Cat 2 and Cat 2A steels are grouped on the same list:

Cat 1: "Post-weld heat treatment may degrade heat-affected zone strength and toughness. Pretesting of specific welding and post-weld heat procedures is recommended to assure optimization of the final property levels."

Cat 2: "It is important to note that this grade of steel may be susceptible to cracking in the heat-affected zone of welds during post-weld heat treatment (stress relief) or elevated temperature service. Also, post-weld heat treatment or elevated temperature service may degrade heat affected zone toughness. Therefore, Mittal Steel USA-Plate recommends that careful consideration be given to these phenomena by competent welding engineers before application."

Cat 2A: "It is important to note that this grade of steel may be susceptible to cracking in the heat-affected zone of the welds during post-weld heat treatment (stress relief). Therefore, Mittal Steel USA-Plate recommends that careful consideration be given to this phenomenon by competent welding engineers before stress relieving is applied to weldments of this grade. Also, it is not recommended for service at temperatures lower than -50° F or higher than 800° F."

Cat 3: "Mittal Steel USA-Plate Abrasion Resistant Steels should not be post-weld heat treated (stress relieved) because such heat treatment will reduce the hardness of the steel."

Cat 1 Steels

A225 Grade C	A633 Grade E	A841 Grade B Class 1
A225 Grade D	A656 Grade 50 Type 3	A841 Grade A Class 2
A242 Type 1	A656 Grade 50 Type 7	A841 Grade B/Class 2
A514 Grade A	A656 Grade 60/Type 7	A852
A514 Grade P	A656 Grade 70/Type 7	A871 Grade 60 Type II#
A517 Grade A	A656 Grade 80/Type 7	A871 Grade 65 Type II#
A517 Grade E	A678 Grade D	A945 Grade 50
A517 Grade P	A709 Grade HPS 50W	A945 Grade 65
A572 Grade 42 Type 2#	A709 Grade HPS 70W	API 2H Grade 42
A572 Grade 50 Type 2#	A724 Grade A	API 2H Grade 50
A572 Grade 55 Type 2#	A724 Grade B	API 2Y Grade 50
A572 Grade 60 Type 2#	A724 Grade C	API 2Y Grade 50T
A572 Grade 65 Type 2#	A737 Grade B	API 2Y Grade 60
A588 Grade A	A737 Grade C	API-2MT-1
A588 Grade B	A738 Grade A	API-2W Grade 42
A612	A738 Grade B	API-2W Grade 50
A633 Grade A	A808	API-2W Grade 50T
A633 Grade C	A841 Grade A Class 1	API-2W Grade 60

Cat 2 & Cat 2A Steels*

A514 Grade B	SPA-90
A514 Grade F	T-1
A514 Grade H	T-1 Type A
A514 Grade Q	T-1 Type B
A517 Grade B	T-1 Type C
A517 Grade F	LQ-130
A517 Grade H	LQ-690Z
A517 Grade Q	Spartan I
A709 Grade HPS 100W	Spartan II
A710 Grade A Class 3	Spartan III
A736 Grade A Class 3	HSLA 80 MIL-S-24645A
	HSLA 100 MIL-S-24645A

* Distinctions between Cat 2 and Cat 2A are recommendations on in-use temperature limits; risk of PWHT equal.

Cat 3 Steels

T-1 Grade 321HB	T-1 Type A Grade 321HB
T-1 Grade 340 HB	T-1 Type A Grade 340 HB
T-1 Grade 360 HB	T-1 Type A Grade 360HB

The VSR TECHNOLOGY GROUP is our Vibratory Metal Stabilization Equipment Division. This unique, non-thermal method of stress relief uses non-destructive mechanical energy, generated by the tightly controlled amplitude and force output of a high frequency vibrator, to induce accelerated granular migration within weldments, castings, forgings, and other metal components in order to redistribute internal stresses.

The MATERIALS MANAGEMENTS GROUP is our Powder and Bulk Solids Handling Division for products and equipment used in the storage, transporting and processing of bulk solid materials. The equipment we offer includes conveyor components and accessories, power transmission and motion control products, level detection and measurement products, and vibrators and aerators to prevent or solve bulk solids flow problems. We offer over 10,000 line items in 8 product categories.

The TOOL GROUP is our General Line MROP Division for supplies and equipment used in maintenance, repairs, operations and production. We can provide over 250,000 line items in 23 product categories. Our 1200 page Tool Store In-Print paper catalog includes many of the items available, and our 60,000 line item Online Tool Store catalog enables our customers to shop and buy a wide range of competitively priced, readily available products.

The SERVICE GROUP is our Product Services/Support Division. Our SHOP SERVICES TEAM is responsible for product modification, rebuilding and repair of portable, stationary and truck mounted power tools, and construction/outdoor equipment.
Our FIELD SERVICES TEAM provides installation, start-up, maintenance and repair, system surveys and training programs for leading manufacturers of powder and bulk solids handling equipment. We are an authorized service center for over 100 of the world's leading manufacturers.