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16. ABSTRACT
In summer 2012 Caltrans replaced a set of six fluid viscous dampers at the Santiago Creek bridge after the earlier set installed in 1997 were reported to be leaking fluid. The recovered dampers were subsequently sent to UCSD for further testing and evaluation for durability and wear. This study extends an earlier examination of de-installed leaking dampers from the Vincent Thomas Bridge (VTB) that were found to exhibit significant component wear of the seals, bearing assemblies. It is anticipated that fluid loss likely results in a loss of operational capability.

The dampers were retested in two stages: Stage I testing performed at 10.5ips in April 2015. Subsequently dampers were retested in Stage II at 41.6ips in September 2015. Upon retesting, the dampers are found in satisfactory operating condition and ‘all’ dampers passed the current multiple qualification criterion outlined by Caltrans. Proof testing at 10.5ips (stage I) and subsequently at fully rated 41.6ips (stage II) suggests that despite the large differences in visual appearance of fluid leakage in dampers, the performance characteristics are similar; any differences are rather subtle and no clear distinction could be drawn regarding the operating functionality of the damper from visual examination alone. In fact visual assessments often singled out the wrong dampers as possibly impaired. Thus, while a visual inspection of leakage may be sufficient concern for heightened monitoring – they may not warrant replacement as they lack any thorough qualification procedure.

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Structural health monitoring, Santiago Creek Dampers, Vincent Thomas Bridge, viscous dampers, in-service damper movements

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Final Report.

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Abstract

In summer 2012 Caltrans replaced a set of six fluid viscous dampers at the Santiago Creek bridge after the earlier set installed in 1997 were reported to be leaking fluid. The recovered dampers were subsequently sent to UCSD for further testing and evaluation for durability and wear. This study extends an earlier examination of de-installed leaking dampers from the Vincent Thomas Bridge (VTB) that were found to exhibit significant component wear of the seals, bearing assemblies. It is anticipated that fluid loss likely results in a loss of operational capability.

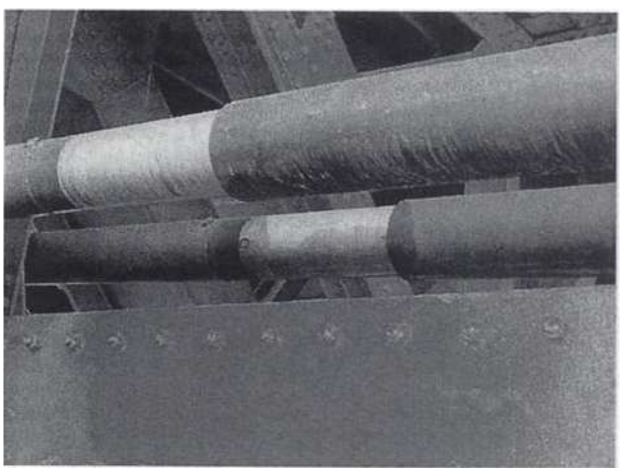
The dampers were retested in two stages: Stage I testing performed at 10.5 ips in April 2015. Subsequently dampers were retested in Stage II at 41.6 ips in September 2015. Upon retesting, *the dampers are found in satisfactory operating condition and 'all' dampers passed the current multiple qualification criterion outlined by Caltrans*. Proof testing at 10.5 ips (stage I) and subsequently at fully rated 41.6 ips (stage II) suggests that despite the large differences in visual appearance of fluid leakage in dampers, the performance characteristics are similar; any differences are rather subtle and no clear distinction could be drawn regarding the operating functionality of the damper from visual examination alone. In fact visual assessment of fluid leakage at various sections of the damper often singled out the wrong dampers as possibly impaired. Thus, while a visual inspection of leakage may be sufficient concern for heightened monitoring, they may not warrant replacement as they lack any thorough qualification procedure.

1. Introduction

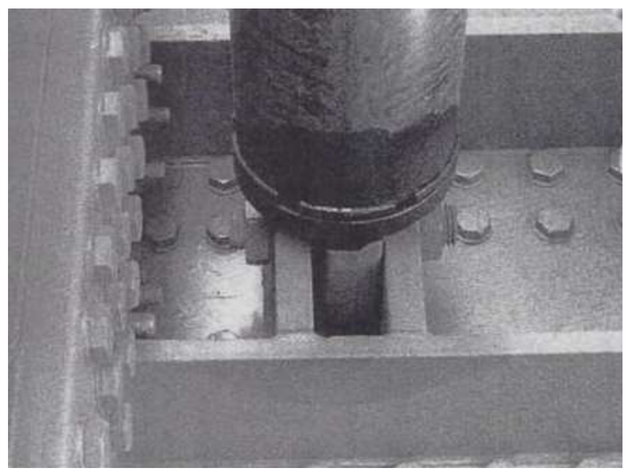
Following the 1989 California Loma-Prieta earthquake, the California Department of Transportation embarked on an ambitious structure retrofit program to improve seismic resistance and performance of bridges using a variety of mitigation measures. In specific cases, seismic isolation and dampers have been utilized.

1.1 Problem Statement: Leaking Dampers

With limited service time in the field the engineer's comfort level with such fluid viscous damper devices remains in its infancy. However, a persistent problem of leaking dampers has emerged in recent years in some California bridges, such as the Vincent Thomas bridge (VTB). The VTB damper retrofit was completed in 1998. However, in early 2001, routine bridge inspections [1] reported evidence of silicone fluid leaking on six dampers. This anomaly appeared to be isolated to the 200-kip dampers on the main suspended span, i.e., the tower – main span truss connections, Figure 1. Fluid leakage varied from potentially excessive leakage at the threaded connection at near mid-length and weepage around the internal seals, Figure 1(a), and at clevis/tang connections, Figure 1(b). In addition to fluid leakage, the protective cover cap screws have come out, either by loosening or shearing on several units. In at least one location, Figure 1(c) the protective cover had shifted from its secured position, revealing a rusted mounting surface. This motion results from the friction between the cover and the nylon spacer on the piston exceeding that between the cover and the now rusted mounting surface.



a)



b)

Figure 1. Evidence of fluid leaking in 200Kip dampers installed on Vincent Thomas bridge. a) Leakage at midsection of bottom dampers tower – deck connection, b) Leakage at clevis at the tower connection, c) Sheared bolts on the damper protective covers at the truss connection and sliding of the cover away from the clevis connection. VTB provided the first detailed examination of the in-service problem of leaking dampers.

c)

Evidence of such leakage may indicate the damper service environment is largely different from what was originally expected [2] with consequences of subjecting the damper assembly and seals to accelerated wear. The damper construction incorporates a series of static and dynamic seals – that may degrade under the actual live loads. The question of seal selection and wear follows from observations that live traffic load induced deflections are of larger amplitudes and higher frequencies than the dampers were expected to experience. In the case of VTB, the vendor's design "ambient vibration" was established at 6 million cycles per year at 0.2 Hz, 0.05 inch double amplitude [3] for total travel of 5miles/year. Documented "ambient" vibrations at the site in 2001 were closer to 0.1 inch peak amplitude at 0.4 Hz, with spikes correlating to heavy truck traffic up to 0.5 inch peak amplitude. Thus, the dampers are experiencing substantially larger ambient motions than anticipated in the design. Despite concurrence with the general idea that larger live loads may be contributing to leakage – inspection evidence reveals several anomalies. For example in Figure 1a we examine the two 200Kip dampers installed side by side at the same tower – main deck truss connection. This adjacent installation guarantees that both dampers are subjected to similar in-service environment but only one was observed to be leaking. We surmise that other factors, for example, the specifics of construction, installation protocol or installation anomalies may also be a contributing factor. The need to replace and re-evaluate these dampers has prompted an earnest investigation of specific causes and possible remedial measures.

1.2 Scope & Relevance of Prior Investigation at UCSD

In Year 2006 Caltrans initiated a program to replace and recover leaking dampers from VTB. Several leaking dampers at the Tower–main deck connections from the West tower location were selected for replacement. Upon replacement, three dampers taken out of service were made available to UCSD for further disassembly and analyses, Figure 2. *All dampers were removed from the south truss at the West tower – main truss* (upper or lower) with the following notes:

SN#004 – West tower, Upper truss (UD), road side
SN#006 – West tower, Lower truss (LD), water side
SN#009 – West tower, Lower truss (LD), road side

This study allowed, for the very first time, to disassemble the de-installed dampers to explore first hand the actual damage and wear incurred in the dampers. Prior studies of in-service anomalies of traffic load deflections and possible fluid temperature rise do not provide a clear link to fluid leakage. Furthermore, despite the larger traffic loads and the fluid temperature rise that applies to the concept of degradation and wear, the wear itself may be severely localized. Silicon fluid loss was assessed at the outset by examining the charge and drain ports. An inspection indicated the following: with SN#009 exhibiting complete functional failure.

1) Damper SN#004 – no loss of fluid
2) Damper SN#006 – partial loss of fluid
3) Damper SN#009 – near complete loss of fluid

Figure 2. VTB 200 kip damper SN#009 as received at UCSD. Note displaced and rotated sleeve cover due to sheared bolts.

2. Evaluation of Recovered Enidine Dampers from Santiago Creek Bridge

A similar leaking problem was identified for dampers installed at the Santiago Creek bridge in Orange County, CA. In summer of 2012 several 160 kip x 30" travel Enidine dampers (Part# SP20553) were taken out of service at the Santiago Creek Bridge and replaced with new dampers. As a continuation and further confirmation of UCSD's prior durability and damage study of dampers recovered from VTB – this set of dampers was delivered to UCSD in Fall 2012 for additional study and is Task 1 of our current Caltrans research project.

2.1 Basic Construct of Enidine Dampers

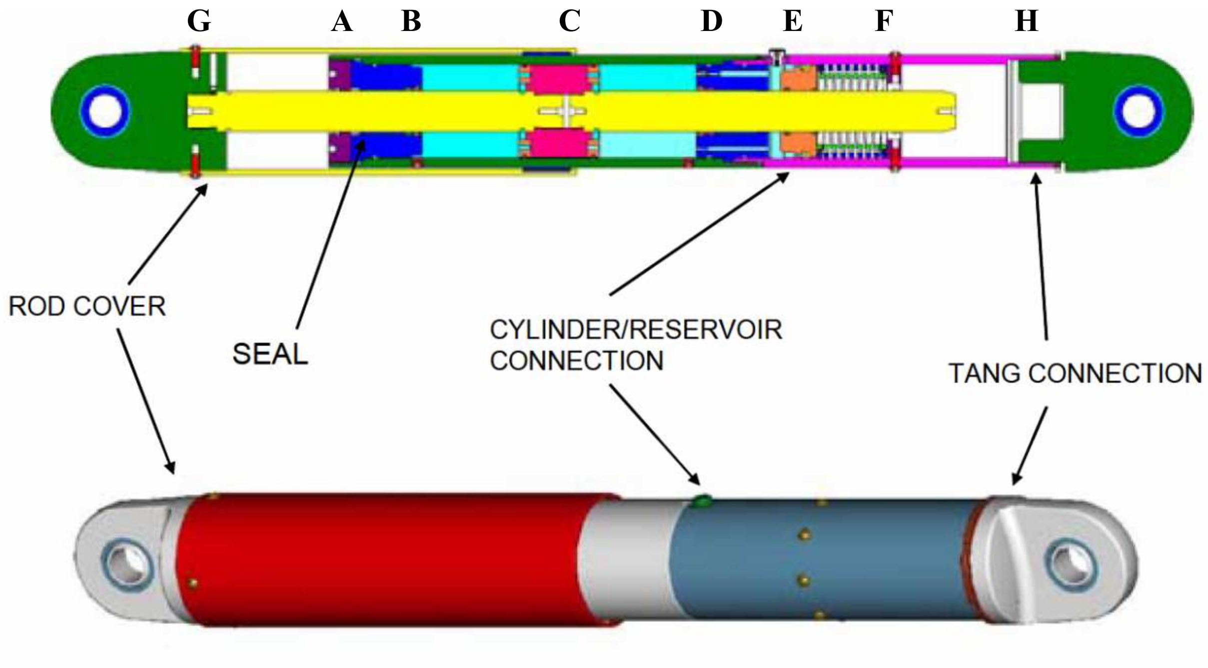


Figure 3. Schematic of a telescoping damper with the operating silicon fluid.

Figure 3 outlines the basic construction of the dampers installed on the Santiago Creek Bridge. It is a telescoping piston type device which incorporates flow of an appropriate high viscosity silicon fluid through orifices in the piston head to absorb energy. A fluid reservoir extension, attached via a threaded connection, providing additional fluid if needed. Since the device is only designed to dissipate energy, it is not intended to carry compressive or other loads. The operating high viscosity silicon fluid is located in the primary chamber, partitioned into two cavities by the piston head. The orifices in the piston head allow constrained fluid flow back and forth during piston movements under live-load conditions or seismic events – thereby providing the resistive force to external events. The energy dissipation is intrinsically linked to the filled fluid chamber and any loss creates operational dead zones where the force versus displacement hysteresis loop indicates negligible resistance and/or energy dissipation.

The damper includes a total of five seals identified in Figure 3 as – labeled **A**, **B** housed in the front bearing, labeled **D** housed in the rear bearing, and labeled **E**, **F** in the spring retainer. It is worth noting that the combination of rear bearing and the spring retainer with the three seals **D**, **E, F** provide a greater bearing support length for the piston rod. Looking ahead to the next subsection, the observed leakage sites are **G, H** – the clevis/tang connections, **C** - the edge of sleeve cover and **E** - the approximate location of the threaded connection. The piston rod length is comprised of two sections threaded into the piston head. The moving piston incorporates a sleeve cover to protect the rod surface finish from the elements and also provide improved stiffness to this moving end. The rod cover is bolted to the tang/clevis assembly and intended to slide smoothly over the cylinder as aided by a Teflon ring at the front end.

2.2 Initial Condition Assessment

The recovered dampers were installed on the Santiago Bridge in September 1997 and after nearly 15 years were removed from service in July 2012. The six dampers removed were delivered to UCSD on 3 pallets, 2 per pallet with the tangs secured in a horizontal position (Note: in service the tangs are in a vertical configuration with a horizontal mounting pin). A visual condition assessment was performed and recorded in Table 1 and shown in Figures 4, 5.

Table 1: Fluid leakage assessment of the recovered dampers from Santiago Creek bridge

Enidine Part# SP20553, 160Kip x 30" travel, α=0.4, Manufactured: 07/1997		
In Service: 09/1997: Removed from Service: 06/2012, shipped to UCSD		
Damper No#	**Condition: Prior to Testing**	**Condition: After Testing**
SN#001	Poor, leakage @**E**, Seepage@**C**	No Change
SN#002	Clean, leakage @**E**	Further leakage @**E**
SN#003	Clean, leakage @**E**	No Change
SN#004	Poor, major leakage @**E**	No Change
SN#005	Poor, leakage @**E,** Seepage@**H**	No Change
SN#006	Poor, leakage @**E**, Seepage@**C,G,H**	Further leakage @**C**

Poor = dirty, multiple fluid stains covering a large surface area of the damper

A visual examination suggested that all dampers were in some distress and fluid leaks observed at different locations as noted in Table 1. Leakage at the threaded connection **(E)** was a common occurrence for all six dampers. Damper SN#001 and SN#006 showed additional weepage at the sleeve cover **(C)** and damper SN#005, SN#006 also exhibit fluid leak stains at the clevis tang locations **(G, H)**.

Figure 4 shows close-up view of the leakage in several dampers. In Figure 4(a),(b) SN#004 is leaking at the threaded connection (E) only while SN#001 also shows weepage at the sleeve cover (C). Looking back to the construction detail, traces of fluid leak at (C) most likely originate from the front bearing failure. Figure 4(c) shows wide disparities in observed leakage in different dampers. Another comparison is shown in Figure 5 for SN#002 and SN#005 where the former looks relatively clean, figure 5(a), and the latter appears to be leaking profusely, figure 5(a), (b). SN#005 condition was to be poor on account of the large stain at the threaded connection (**E**) with additional leak stains at the clevis/ tang – perhaps indicative of leakage at the rear bearing or the reservoir chamber, Figure 5(c).

Any weepage observed on the sleeve cover, and at the tangs is taken to be direct evidence of bearing damage – as the only viable leak path originates from the bearings. Leakage at the threaded connection is somewhat deceptive as the leak path does not traverse any seals, bearings and could stem from construction defects. *We note that thread sealants are employed during the assembly process and these may become embrittled and crack under repeated service loading.*

a)

b)

c)

Figure 4: Inspection of as-received Enidine dampers recovered from Santiago Creek. a) Leakage at the thread in SN#004 and leakage at thread and seepage at sleeve cover in SN#001, b) Close up view of leaks in (a); c) Varying degrees of thread leakage in SN#002 and SN#005. No seepage observed in either damper SN#002, SN#005 sleeve covers.

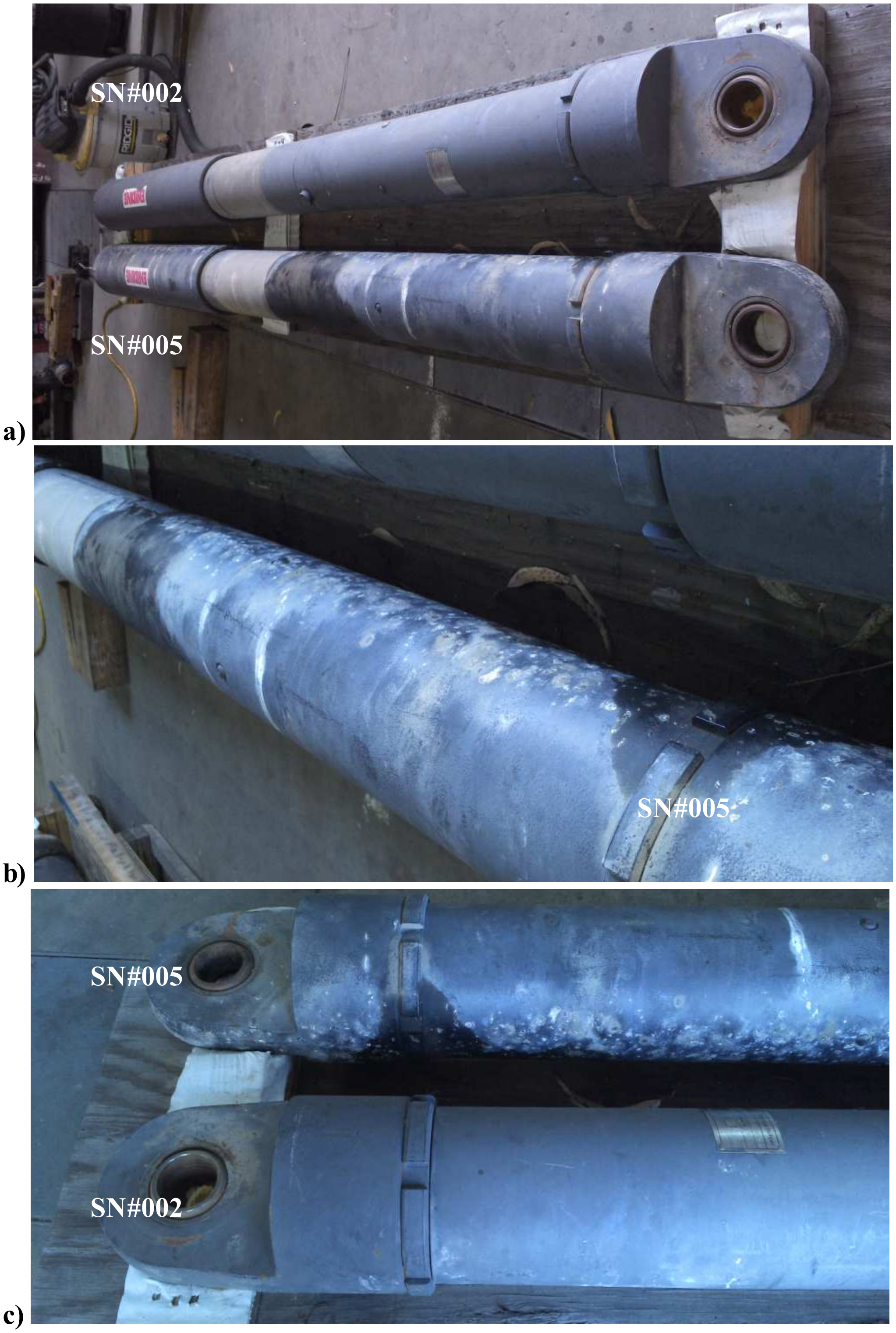
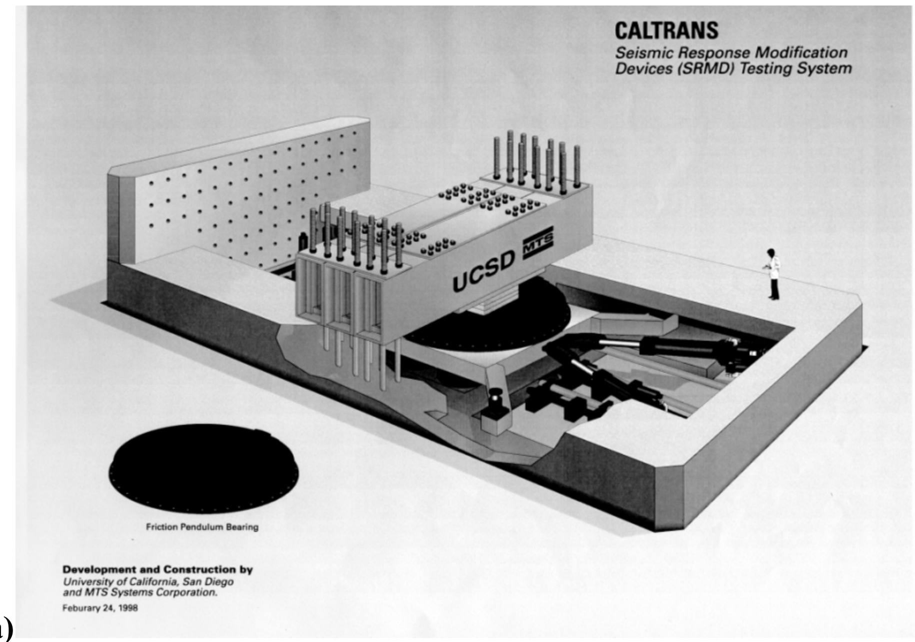


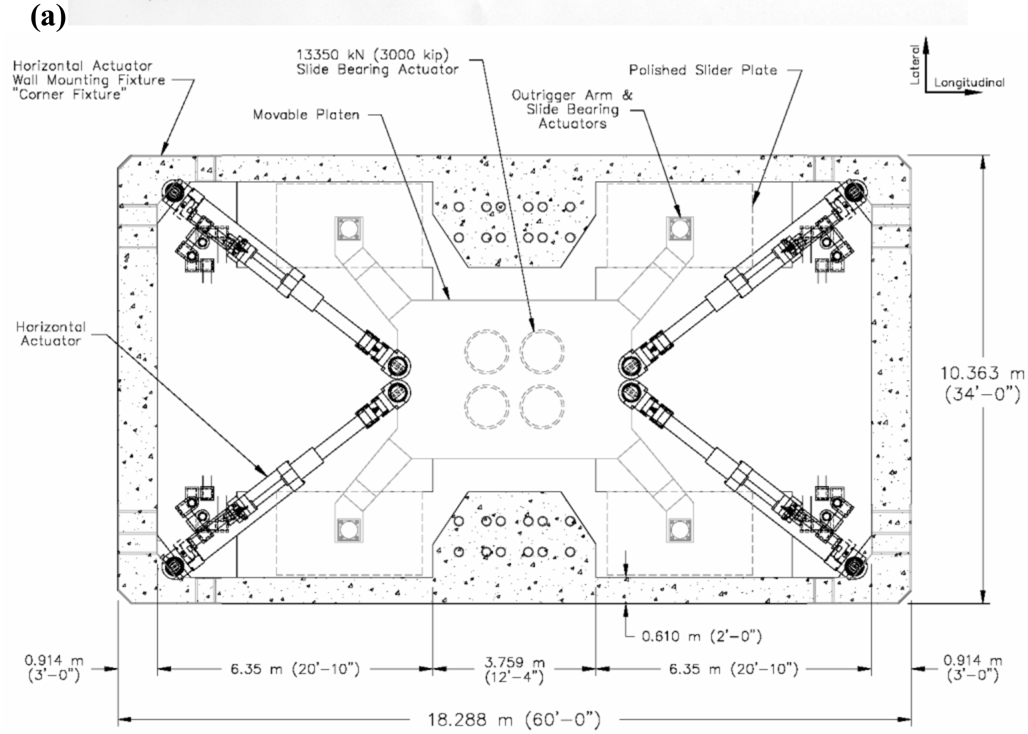
Figure 5: Comparative visual examination of dampers SN#002, SN#005. a) Damper 002 (top) is reasonably clean but 004 (bottom) shows profuse leakage at threaded joint and at clevis/tang connection. b) close-up of leakage at tang connection, c) comparison of 002 and 005 tang.

3. Proof Testing at the Caltrans SRMD

The Caltrans SRMD Test Facility is located at the University of California San Diego. The facility was developed jointly by the California Department of Transportation, the Department of Structural Engineering at the University of California San Diego and MTS Corporation of Eden Prairie, MN and became operational in 1999 after a two-year design and construction phase. An overview of the test machine is illustrated in Figure 6.



(a)



(b)

Figure 6. Schematic and plan view of the SRMD test bay. Dampers are tested in horizontal orientation mounted between the moving platten and the pre-stressed concrete reaction wall.

The test rig allows real time 6-DOF dynamic characterization and consists of a moving platen connected by four hydraulic actuators to a pre-stressed concrete reaction frame (concrete box). The platen slides over four low-friction hydrostatic bearings (less than 2% of vertical force) attached to the floor of the concrete structure. The platen also extends with four steel outrigger arms that support four low-friction sliding actuators at their tops and four at their bottoms. The testing system is completed by two additional reaction structures: a steel cross beam, removable and linked to the concrete box through a tie-down rod system, and a heavily pre-stressed reaction wall on one end of the machine. As shown in Figures 7, 8 the damper device is mounted horizontally, between the moving platen and the concrete reaction wall, for testing.

Figure 7. Overview of SN#004 as mounted for testing and leaking at the threaded connection.

Figure 8 a) SN#006 leaking at the sleeve cover, b) SN#001 leaking at the threaded connection

3.1 Test Protocol at SRMD

As a preliminary performance check, and prior to any proposed scheduled disassembly, all six dampers were tested for a minimum of 5 cycles of +/-11" displacement at target test velocity of 10.5 in/sec (measured 10.467 in/sec). This test protocol was adapted from one prescribed for the replacement Santiago Creek dampers, also proof tested at SRMD in May 2012, requiring sequential testing at 10 in/sec, 20 in/sec and final testing at 40 in/sec for the full rated force of 160 kips. The initial emphasis was to only assess any dead zones in the damper performance (due to fluid loss). This Stage I test cycle was conducted in April 2015 and data reported in Figure 9 (blue curves, labeled SN#_T1). Force is recorded via the in-line Interface load cell and displacement via the two string pots mounted on the damper sleeve and casing.

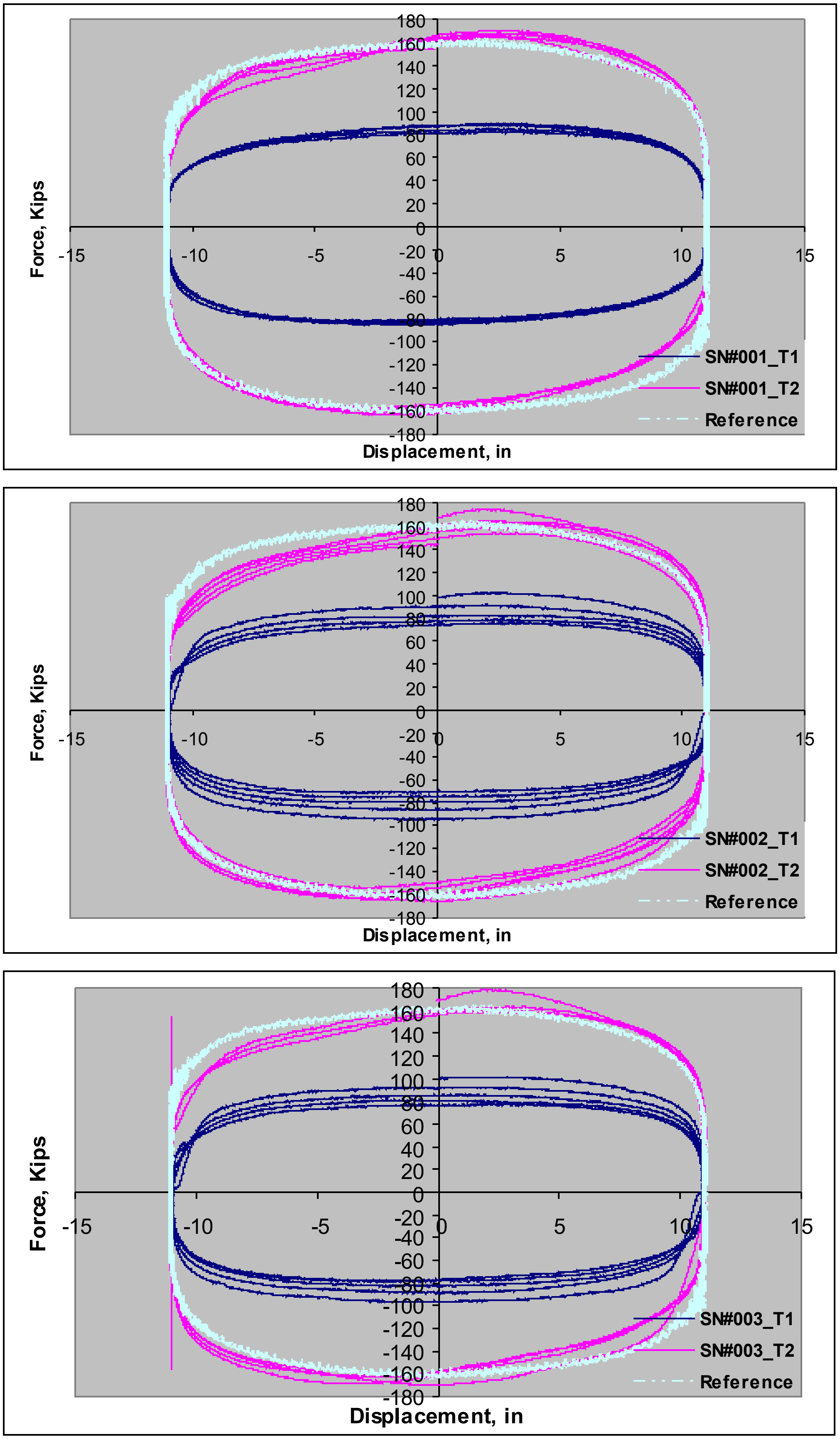
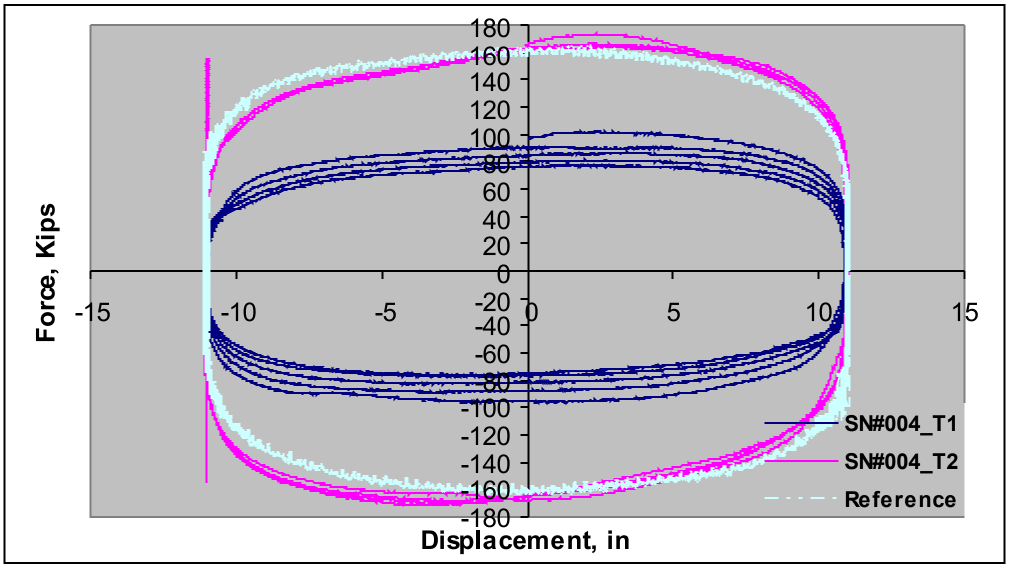
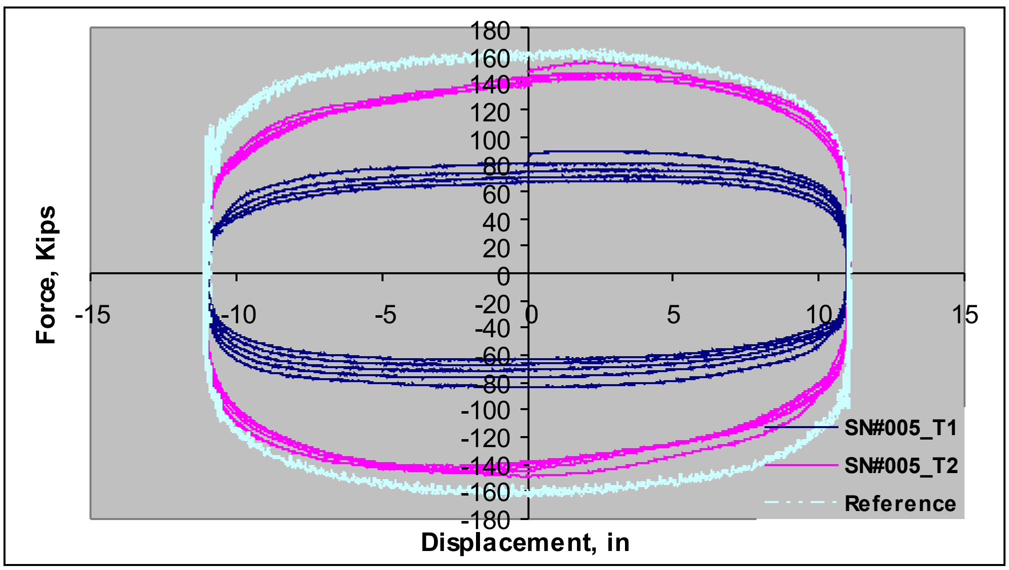


Figure 9. Load displacement plots for the 5 cycle proof testing for **SN#001 – #006** dampers.


Force, Kips
Displacement, in
SN#004_T1
SN#004_T2
Reference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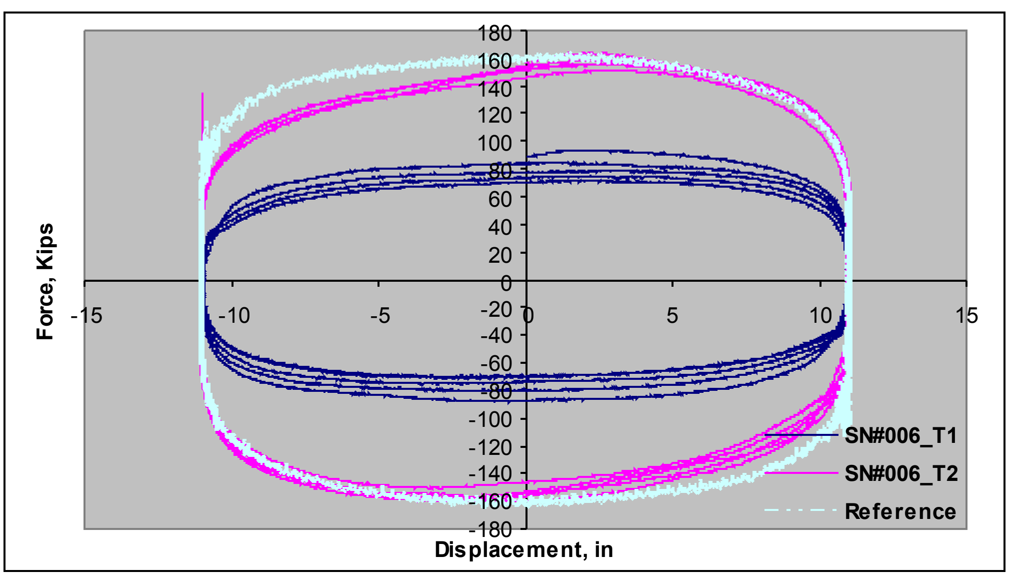

Force, Kips
Displacement, in
SN#006_T1
SN#006_T2
Reference

Looking ahead to the results of the Stage I, the promising results obtained under initial proof testing at 10.5 in/sec, Caltrans recommended retesting the dampers to its fully rated 41.6 in/sec velocity test to determine if dampers are fully compliant with the peak force of 160 kips and the expected Force-Velocity characteristics. In September 2015, all 6 dampers were retested in what will be reported as Stage II data in Figure 9 (pink curves, labeled as SN#_T2).

4. Test Results

The principal results of Stage I (test velocity 10.5 in/sec) and Stage II (test velocity 42 in/sec) testing are presented in Figure 9. A brief overview of Stage I (blue curves) and Stage II (pink curves) test results indicate that dampers exhibit satisfactory Force-Displacement characteristics at the requisite test velocity. To illustrate this graphically, a reference Force-Displacement curve (Light Blue) for the stage II testing is superimposed on Figure 9. A quick visual examination shows fairly consistent overlap of the reference curve over the Stage II test data for SN#001, 002, 003, 004, 006. A quick examination also reveals that the Stage II test curve for SN#005 consistently underperforms the reference curve. As shown later, damper SN#005 indeed failed the current acceptance criterion outlined by Caltrans.

There are obvious differences in performance and damper condition following Stage I and Stage II testing. For the purpose of clarity, the results are presented separately, so that specific features can be described for individual stages. In what follows, a rigorous analysis is presented for the stage I data and each damper performance analyzed. This is repeated for stage II results along with additional features observed.

4.1 Stage I Testing (V=10.5 in/sec)

A brief description of the test loops follows: SN#001 exhibits an extremely tight loop with force vs. displacement performance fairly consistent over the 1st -5th cycles. SN#002 – SN#006 all show similar performance with 1st cycle exhibiting high peak force and decaying over the 2nd – 5th cycle. A rather negligible dead zone is observed for SN#002 and SN#003 in the first cycle which disappears in the subsequent cycles. Nonetheless, both SN#002 and SN#003 exhibit performance similar to the rest of the dampers. Figure 10 shows a comparative look of the 1st complete cycle response of all the dampers. We note that SN#003 and SN#004 exhibited marginally higher peak force; the rest have a slightly lower, and similar, peak force. The dead zone is clearly visible for SN#002 (small) and SN#003 (larger).

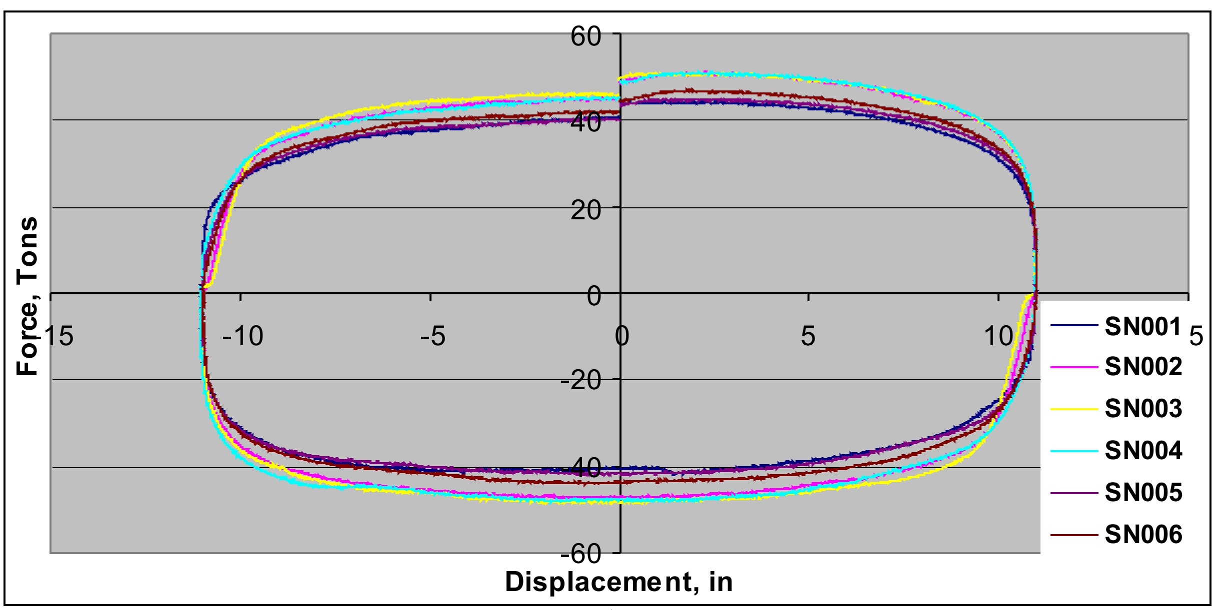


Figure 10. Stage I test performance of the 1st cycle behavior of SN#001 – #006 dampers.

The peak force data, as recorded at displacement = 0 is further recorded in Table 2, with +value denoting the pull cycle (i.e. damper extension) and –value denoting the push cycle (damper compression). The tabulated peak forces of Table 2 are further illustrated graphically in Figure 11. SN#001 indicates stable to mildly increasing peak force in what is clearly noted as anomalous behavior at variance with the remaining dampers. SN#002 – SN#005 indicate nearly similar response of gradually decaying peak force. The range of force drop is 10.6-13.21 short tons (21.2 – 26.42 kips), with the largest drop exhibited by SN#002 and the smallest drop exhibited by SN#006.

Table 2: Stage I tabulated data for peak forces (kips at displacement = 0) for all dampers.

SN#	Cyc+1	Cyc-1	Cyc+2	Cyc-2	Cyc+3	Cyc-3	Cyc+4	Cyc-4	Cyc+5	Cyc-5	Cyc+6
001	87.38	-81.34	81.14	-80.52	83.30	-82.50	86.94	-83.10	88.06	-84.60	88.78
002	97.38	-94.24	90.20	-86.20	81.84	-79.16	77.34	-74.46	74.00	-70.84	70.96
003	99.28	-96.60	91.58	-88.70	85.12	-82.68	80.38	-77.98	76.46	-77.28	77.42
004	96.78	-94.98	90.30	-87.40	84.36	-81.70	79.46	-76.36	76.32	-77.84	73.48
005	86.94	-83.20	79.82	-76.04	74.30	-70.60	70.26	-66.66	66.86	-63.08	63.80
006	88.38	-87.48	83.84	-79.70	77.48	-73.62	73.54	-70.20	70.04	-69.56	67.18

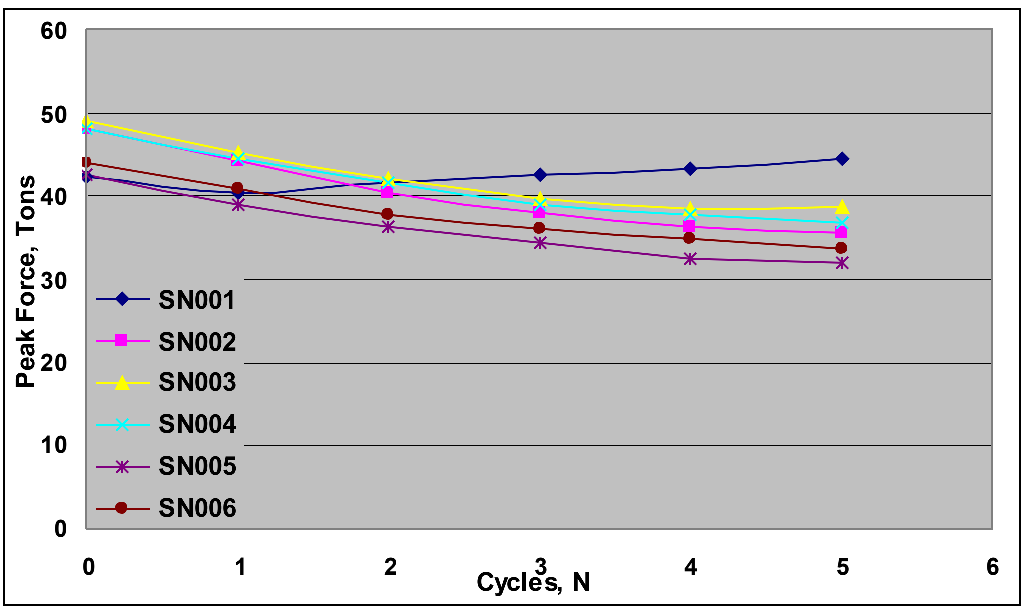


Figure 11. Stage I Peak force decay in 1st – 5th extension cycle for SN#001–SN#006 dampers.

4.2 <u>Stage II Testing (V=41.6 in/sec)</u>

A comparison between the experimental test loops at V=42 in/sec (pink curves) and the ideal reference force curve (light blue) is illustrated graphically in Figure 9. A visual examination shows fairly consistent overlap of the reference curve over the Stage II test data for SN#001, 002, 003, 004, 006. The experimental force curves underperform slightly at force reversals (i.e., corresponding to stroke reversals at the +/- 11in displacement) for SN#001, #002, #003, #004, #006 and approach or exceed ideal performance at peak velocity at mean displacement=0. Similarly, a quick examination also reveals that the Stage II test curve for SN#005 consistently underperforms the reference curve, never approaching the ideal curve during any stage of the +/-

11 in. travel. As shown later in summary discussion, Section 6, damper SN#005 indeed passes the current acceptance criterion outlined by Caltrans.

Figure 12 shows a comparative look of the 1st complete cycle response of all the dampers. We note that contrary to stage I testing, no dead zone is observed for SN#002, SN#003 during the first cycle. We also note, as before, that SN#003 (yellow) and SN#004 (light blue) exhibit marginally higher peak force; the rest have a slightly lower, and similar, peak force. Once again SN#005 has the lowest peak force.

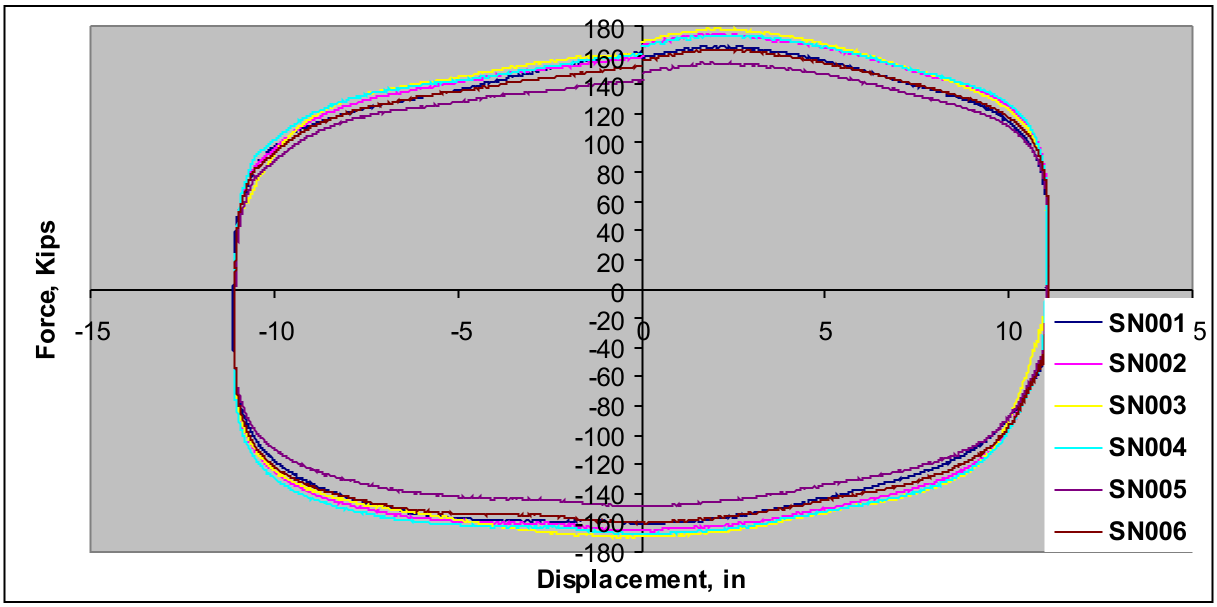


Figure 12. Stage II test performance of 1st Cycle behavior for SN#001 - #006 Dampers

A noteworthy observation is the shear failure and stripping of the damper sleeve screws, occurring just prior to the onset of the 5th cycle, in SN#003, #004 and #006 dampers. Looking back, Figure 3 shows that the damper sleeve is affixed to the clevis via 4 screws (also labeled as location **G**). Similar stripping events are observed on VTB, Figure 1©, and in VTB recovered dampers, Figure 2. This shear failure is observed at the end of the compression cycle, during load reversal into the tension cycle, and just prior to the onset of the 5th cycle. This is evident form the near vertical force curve, at the end of the 4th cycle, at -11 in. displacement in Figure 9 for the SN#003, #004 and #006 dampers. Once the sleeve is stripped, no further displacement can be recorded from the sleeve mounted displacement sensor resulting in the vertical force curve.

Figure 13(a) shows an overview of the displaced sleeve cover as recorded at the conclusion of the 5 cycle test for SN#003 damper. Figure 13(b), shows the two sheared bolts that can be seen close up from this viewing angle. This sleeve stripping event allows a look into the cavity to explore the damper front bearing (Figure 3, location A). Figure 14(a) shows a clean sleeve interior and the front bearing for SN#003 damper and Figure 14(b) shows an oily sleeve interior typical of slight leakage at the front bearing. This fluid leakage condition assessment was indicated earlier in Table 1.

Figure 13. (a) Overview of stripped sleeve, and (b) close up of sheared bolts on SN#003 damper.

Figure 14. (a) inside view of the dry sleeve cover and clean front bearing for SN#003 damper, b) inside view of the oily sleeve cover for SN#006 damper indicating mild leakage at front bearing.

It is necessary to explore the origin and, more importantly, the impact of such sleeve failures on current test results and subsequent service. The sleeve failure derives from increased frictional events at the sleeve-cylinder interface and the binding of the sleeve to the telescoping cylinder column bending during the compression cycle. Open air damper installations cause weathering of the cylinder surface and debris accumulation can significantly increase the surface roughness leading to higher frictional loading. The binding effects are specific to initial construction tolerances in the damper build along with any subsequent wear that may further exacerbate the gaps between piston rods and bearings. A quantitative estimate of the binding and frictional forces necessary to cause complete shearing failure of the sleeve screws is

No. of screws (N) x Screw cross-sectional area x Material Shear Strength = 12.966 Kips
Where N = 4,
Cross-Sectional Area, πr^2, = 0.0767in^2 where r = 5/32", and
Shear Failure Strength, τ, 304 stainless steel = 42.26Ksi

The impact of sleeve failure on current test result is discussed in the next section. Loss of sleeve cover in service will result in a loss of piston rod stiffness, thereby exhibiting greater bending, and result in significantly greater pressure and wear at the front bearing location. Such a failure will be deemed as a terminal event as this inevitably leads to bearing failure and loss of all damper fluid. As a prior example from the field failures, Figure 2 shows a recovered VTB damper with a stripped sleeve with a complete loss of damper fluid.

The peak force data, as recorded at displacement = 0 is recorded in Table 3, with +value denoting the pull cycle (i.e. damper extension) and –value denoting the push cycle (damper compression). The tabulated peak forces of Table 3 are further illustrated graphically in Figure 15. SN#001 indicates very consistent peak force over 5 cycles of testing with minimal variation of about 10kips. We note that dampers with stripped sleeves (i.e., SN#003, SN#004, SN#006) show larger peak force drops in the later 4^{th} and 5^{th} cycles.

Table 3: Stage II tabulated data for peak forces (kips at displacement = 0) for all dampers.

SN#	Cyc+1	Cyc-1	Cyc+2	Cyc-2	Cyc+3	Cyc-3	Cyc+4	Cyc-4	Cyc+5	Cyc-5	Cyc+6
001	158.67	-160.74	161.39	-161.25	163.97	-159.94	165.51	-156.20	162.52	-153.93	154.03
002	166.74	-165.09	159.11	-161.08	159.62	-159.59	154.60	-153.68	149.38	-148.93	143.47
003	169.38	-169.35	160.72	-159.57	155.99	-158.65	158.71	-161.40	151.08	-151.31	146.20
004	165.85	-167.57	160.85	-164.56	163.37	-165.28	160.87	-164.75	152.84	-151.40	145.60
005	147.85	-148.61	142.77	-144.46	144.11	-142.20	141.06	-139.27	139.82	-138.35	136.97
006	156.31	-159.52	152.56	-156.53	151.78	-153.55	153.78	-154.68	146.36	-145.85	134.06

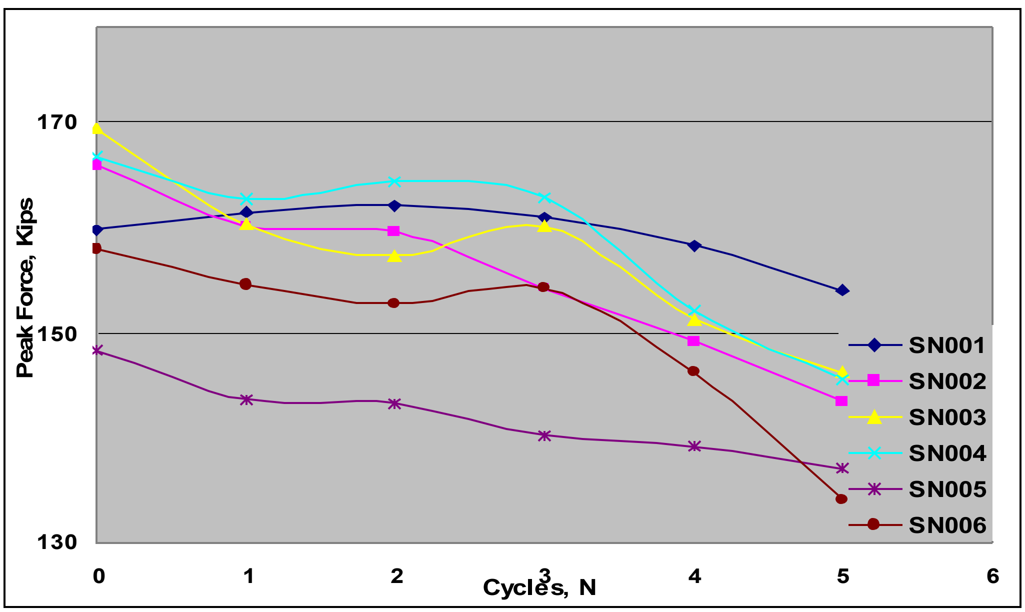


Figure 15. Stage II Peak force decay observed for cycles 1-5 for SN#001–SN#006 dampers.

5. Discussion of Results

It is apparent from the test results that despite the large differences in visual appearance of fluid leakage in dampers, the performance characteristics are similar; any differences are rather subtle and no clear distinction could be drawn regarding the operating functionality of the damper from visual examination alone. In fact visual assessments often singled out the wrong dampers as possibly impaired. Thus, while a visual inspection of leakage may be sufficient concern for heightened monitoring, they may not warrant replacement as they lack any thorough qualification procedure. Even the finite loss of fluid, as noted for SN#002 and SN#003 in stage I testing may not be sufficient criterion for replacement. Furthermore, this dead zone was not detected during stage II testing. A likely explanation is that the fluid reservoir still contains fluid and replenished the lost fluid in the main chamber during the extended +/-11 in. stage I test stroke. A fluid loss criterion requires calibration and quantification to evolve as an effective tool.

The results suggest that mere visual protocols to qualify leaking dampers to be taken out of service are insufficient. It appears that full retesting and comparison with acceptance protocols can be a low cost pathway to salvaging still functional dampers. To accomplish that objective - the damper performance for the current set is rated as $F=CV^n$, where C=35.88 for rated max F=160 kips at V=42 in/sec and n=0.4 [4]. In the current Caltrans mandated practice, the following practices are accepted [5]:

Criterion **I**: EDC value above 90% of the theoretical value for the first cycle, and
Criterion **II**: EDC no less than around 75% after 5 cycles.
Criterion $\mathbf{II_{alterante}}$: the average of all 5 cycles to be no less than around 80% is allowable

What follows is an attempt to qualify the functional efficacy of dampers via criterion **I** and/or **II**. Using the Stage I test velocity of 10.467 in/sec, computed F =91.79 kips and $F_{90\%}$ =82.61 kips. This corresponds to initial EDC as approximately =3616 kips.in and $EDC_{90\%}$ =3255 kips.in as the lower acceptable bound for the 1^{st} cycle. Furthermore the $EDC_{75\%}$ for the 5^{th} cycle = 2712 kips.in and $EDC_{80\%}$ = 2893 kips.in for the alternate procedure of 5 cycle summed average.

Table 4. Stage I data qualification criterion for replacement, recovered dampers

	Operative Cycle, EDC (Kips.in), Fave (Kips)					**Criterion**	
Damper	**1^{st}**	**2^{nd}**	**3^{rd}**	**4^{th}**	**5^{th}**	**I**	**II**
SN#001	EDC=3270 F_{ave}=81.134	EDC=3202 F_{ave}=81.825	EDC=3254 F_{ave}=84.718	EDC=3326 F_{ave}=85.504	EDC=3340 F_{ave}=86.550	**Pass**	**Pass**
SN#002	EDC=3697 F_{ave}=92.059	EDC=3368 F_{ave}=83.896	EDC=3135 F_{ave}=78.179	EDC=2958 F_{ave}=74.328	EDC=2809 F_{ave}=70.738	**Pass**	**Pass**
SN#003	EDC=3764 F_{ave}=94.067	EDC=3446 F_{ave}=86.779	EDC=3233 F_{ave}=81.566	EDC=3066 F_{ave}=77.314	EDC=3013 F_{ave}=77.284	**Pass**	**Pass**
SN#004	EDC=3762 F_{ave}=92.726	EDC=3467 F_{ave}=85.968	EDC=3239 F_{ave}=80.540	EDC=3030 F_{ave}=76.372	EDC=2906 F_{ave}=74.309	**Pass**	**Pass**
SN#005	EDC=3297 F_{ave}=81.717	EDC=3031 F_{ave}=75.035	EDC=2841 F_{ave}=70.428	EDC=2664 F_{ave}=66.738	EDC=2523 F_{ave}=63.394	**Pass**	**Fail** **Δ<1%**
SN#006	EDC=3427 F_{ave}=85.667	EDC=3155 F_{ave}=78.653	EDC=2956 F_{ave}=73.723	EDC=2777 F_{ave}=70.336	EDC=2690 F_{ave}=68.266	**Pass**	**Pass**

The tabulated results of such qualification procedure are listed in Table 4. Damper SN#001, #002, #003, #004 passed all criteria **I**, **II** and the $\mathbf{II}_{alternate}$. Damper #006 passed Criterion **I,** and the $\mathbf{II}_{alternate}$. Damper SN#005 passed criterion **I** but failed marginally both criterion **II** and $\mathbf{II}_{alternate}$. We note that damper SN#001 is anomalous in that even though the 1st cycle underperforms, it retains or marginally increases its EDC over the 2nd – 5th cycle and handily exceeds criterion **II** and $\mathbf{II}_{alternate}$.

A similar quantification following stage II testing produces the tabulated results in Table 5. Using the Stage **II** test velocity of 41.60 in/sec, computed F =159.40 kips and $F_{90\%}$ =143.46 kips. This corresponds to initial EDC as approximately =6278 kips.in and $EDC_{90\%}$ =5650 kips.in as the lower acceptable bound for the 1st cycle. Furthermore the $EDC_{75\%}$ for the 5th cycle = 4709 kips.in and $EDC_{80\%}$ = 5022 kips.in for the $\mathbf{II}_{alternate}$ procedure of 5 cycle summed average. Thus it is our conclusion that apart from, and despite, the sleeve cover failure "all" dampers passed Caltrans mandated qualification protocol. An acceptable force curve response for SN#001, #002, #003, #004 and #006 dampers was assured earlier by a visual comparison in Figure 9. We recall from test results of Figure 9 and the peak force data of Table 3 that SN#005 exhibited the lowest force and EDC. Nonetheless, a quick review of the $F_{90\%}$ =143.46 Kips criterion for the first cycle of SN#005 in Table 3 and an EDC comparison of Table 5 indicates that the damper indeed passed both the current criterion **I** and criterion **II** of the current Caltrans mandated qualification regime.

Table 5. Stage II data qualification criterion for replacement, recovered dampers

	Operative Cycle, EDC (Kips.in), Fave (Kips)					**Criterion**	
Damper	**1st**	**2nd**	**3rd**	**4th**	**5th**	**I**	**II**
SN#001	EDC=6141	EDC=6224	EDC=6265	EDC=6231	EDC=6134	**Pass**	**Pass**
SN#002	EDC=6375	EDC=6261	EDC=6149	EDC=5916	EDC=5735	**Pass**	**Pass**
SN#003	EDC=6436	EDC=6149	EDC=6142	EDC=6200	EDC=5806	**Pass**	**Pass***
SN#004	EDC=6468	EDC=6421	EDC=6452	EDC=6359	EDC=5860	**Pass**	**Pass***
SN#005	EDC=5713	EDC=5597	EDC=5506	EDC=5425	EDC=5377	**Pass**	**Pass**
SN#006	EDC=6097	EDC=6042	EDC=5958	EDC=5968	EDC=5623	**Pass**	**Pass***

**indicates damper sleeve sheared off at the onset of the tension cycle.*

Current project test results show there may be sufficient ambiguity and false positives if the fluid leakage criterion is used primarily *in lieu* of stringent retesting. In the current case of replaced dampers all dampers appeared to be in varying stages of duress with abundant traces of leakage, Nonetheless, all dampers re-qualified per the Caltrans F-V test and only one damper marginally failed (**Δ<1%**) following stage **I** qualification but passed following stage **II** testing. Thus, it is our conclusion that apart from, and despite, the sleeve cover failure "all" dampers passed Caltrans mandated qualification protocol.

References:

1. Caltrans VTB Inspection Reports, *private communication with Dr. Charles Sikorsky*

2. Sheng, L-H. and Lee, D., (2003) Performance of Viscous Dampers and its Acceptance Criteria, in Advancing Mitigation Technologies and Disaster Response for Lifeline Systems, Ed. J.E. Beavers, ASCE Conf. Proc. Earthquake Engineering, Long Beach, CA, p.1031-1039, 2003

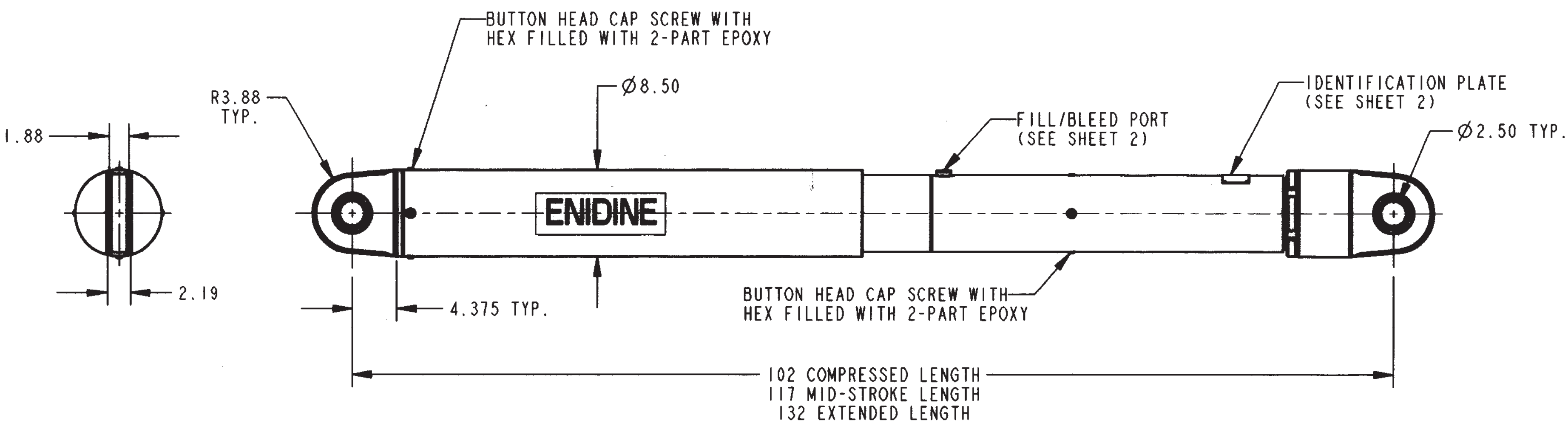
3. Domange, B., Enidine US Patent 7,264,095, Vibration and Displacements Damper, in particular for Cable Stays. Issue Date September 4, 2007

4. Vendor supplied design data, Santiago Creek Build, included as Appendix A

5. Caltrans EDC Qualification Protocol, *Private communication with Dr. Don Lee*

Appendix

REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL
A	REVISED	06 DEC 96	B. BUCHOLTZ
B	REVISED	06 FEB 97	B. BUCHOLTZ
C	REVISED, ADDED SHEET 2	08 MAR 97	B. BUCHOLTZ
D	REVISED	19 MAR 97	B. BUCHOLTZ



IMAGED: 9-17-02
BY: db

8. REF: SANTIAGO CREEK BRIDGE #55-0823 R/L.

7. REF: PROJECT EA NO. 12-111000 EASTERN TRANSPORTATION CORRIDOR.

6. FORCE -VELOCITY CHARACTERISTIC: F = 35.88 V exp (0.4).

5. STROKE LENGTH: 30 IN. (±15 IN.)

4. LOAD RATING: 160 KIPS AT 42 IPS.

3. OPERATING FLUID: INERT SILICONE.

2. CMTR REPORTS SUPPLIED FOR ALL STRUCTURAL MATERIALS.

1. FOR DESIGN DETAILS, SEE TECHNICAL SPECIFICATIONS.

NOTES: UNLESS OTHERWISE SPECIFIED

P/N SP20553

030897

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APPROVED	J. PANER	7 FEB 97
CHECKED	J. PANER	29 OCT 96
DRAWN	J. HILL	29 OCT 96

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