U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

Memorandum

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Subject: DRAFT FINAL REPORT: VRTC-DCD9143 for EA08-018 and PE08-041 "Evaluation of Changes in Steering Effort Resulting from Corroded Intermediate Shafts in 2002-2004 Kia Sedonas and 2004 Toyota Siennas"

Date: SEP 2 1 2009

From: Roger Saul Roger A Saul
Director
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Reply to Attn. Of: NVS-310

To: Kathleen DeMeter
Director
Office of Defects Investigation

NVS-210

Attached is the draft copy of the subject final report for your review. We will finalize the report after comments have been received from your office.

Attachment: (1)
Draft Final Report

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MEMORANDUM REPORT for VRTC-DCD9143

Evaluation of Changes in Steering Effort Resulting from Corroded Intermediate Shafts in 2002-2004 Kia Sedonas and 2004 Toyota Siennas

1.0 – INTRODUCTION

The Office of Defects Investigation (ODI) received complaints of increased and irregular steering effort in model year 2002-2004 Kia Sedonas and model year 2004 Toyota Siennas. Engineering Analysis EA08-018 (Sedona) and Preliminary Evaluation PE08-041 (Sienna) were opened by the Office of Defects Investigation (ODI) to further understand the safety consequences of the defect. This report will communicate the testing and analysis conducted by the National Highway Traffic Safety Administration's (NHTSA) Vehicle Research and Test Center (VRTC).

2.0 – BACKGROUND

The pattern of steering binding observed in these vehicles is caused by the loss of lubrication and ensuing corrosion in the articulating universal joints of the steering intermediate shafts. In the case of the Sedona, the seals protecting the bearings deteriorate and allow the intrusion of moisture. The moisture displaces the bearing lubricant and causes wear and corrosion. In the case of the Sienna, bearings also wear and corrode, however the condition is not caused by worn seals. The Sienna uses a slightly different design that includes plastic thrust pins inserted into the ends of the bearing caps. These pins push equal and opposite forces onto the joint to keep it centered. The pins become worn and allow the joint to shift to one side to create a gap between the seal and the bearing cap, which permits the intrusion of moisture. The loss of lubrication and subsequent corrosion cause the joint to bind, thus increasing the steering effort. The onset of the defect in both vehicles is typically gradual.

3.0 – OBJECTIVES

The objectives for the VRTC were:

1) To determine whether a safety risk is associated with this vehicle in the event that steering effort increases;
2) To confirm that the irregular, increased steering effort is caused by corrosion in the universal articulating joint of the intermediate shaft;

3) To conduct physical testing of complaint components and quantify the effects of the defect.

4.0 - PROCEDURES

4.1 Visual Inspection – Several complaint intermediate steering shafts from both Sedonas and Siennas were submitted to ODI from vehicle owners. These shafts were sent to the VRTC for visual inspection and testing. The shafts were installed into two test vehicles: a 2004 Toyota Sienna (Figure 1) and a 2004 Kia Sedona (Figure 2).

Figure 1 – Test Vehicle #1 2004 - Toyota Sienna

Figure 2 - Test Vehicle #2 - 2004 Kia Sedona

4.2 Vehicle Testing – All submitted complaint intermediate steering shafts were installed into vehicles for testing to quantify the consequences of steering binding. Two types of tests were conducted:

4.2.1 Suspended Static Steering Test – This test was intended to isolate and measure the hand wheel (steering wheel) force required to turn the wheel. By suspending the vehicle on a lift, frictional losses in ball joints, tires, road surfaces, and vehicle loading could be held essentially exogenous to the data. A non-complaint steering shaft was used to establish baseline data. Following the baseline test, each of the complaint steering shafts were installed and tested against this baseline.

Data acquisition equipment was installed to monitor steering wheel input torque and steering wheel angle. The test procedure called for the steering wheel to be rotated counter-clockwise all the way left for the start of the test. Once data acquisition began, the wheel was turned clockwise (to the right) at either a normal rate or a rapid rate, depending on the test. When the operator rotated the wheel to the right stop, the wheel was to then be turned counterclockwise until it reached the left stop. At this point the test was concluded. For this testing sequence, the engine was usually operating at idle unless otherwise noted.

4.2.2 Dynamic Steering Gain Test – This test was designed to ascertain the amount of hand wheel force required by the driver to achieve defined lateral acceleration thresholds, expressed as a ratio to gravity (G) in real-world road testing. A non-complaint steering shaft was tested to establish the baseline forces required, followed by testing of each of the complaint steering shafts. Tests were conducted with the vehicles loaded to a lightly loaded vehicle weight (LLVW) and also loaded to the gross vehicle weight rating (GVWR) per the manufacturer's specification. The gross axle weight rating (GAWR) was used to proportionally distribute the ballast weight between the front and rear axles. The steering gain testing consisted of driving the vehicles on a straight skid pad. Tests were conducted with the engine running to provide normal power steering assist and then with engine off, transmission in neutral, to simulate loss of power assist. A slalom type maneuver was performed, and the vehicle speed at the start of each test was approximately 40 mph. The vehicles then coasted down to around 30 mph during the test.

5.0 - RESULTS

5.1 Visual Inspection – The intermediate shaft consists of two painted shafts, joined by a universal joint (Figures 3 and 4). The joint facilitates off-axis articulation and rotation. The universal joint consists of two pairs of cylindrical bearings arranged in a cross pattern. Each axis of the cross is mated to pivoting receivers that are joined to the respective ends of the shaft. The shaft can then pivot and rotate about the universal joint. The bearings are sealed to prevent the entry of contaminants. In all observed complaint shafts, on at least one axis of bearings the seals had been breached and corrosion of the internal needle bearings had occurred. A sample of the corroded bearing compared to a non-corroded bearing can be seen in Figures 5 and 6. The Sienna design incorporated hard plastic thrust pins inserted into each end of the joint to maintain equidistant spacing. Sienna joints that were binding exhibited worn thrust pins (Figure 7).

Figure 3 - Toyota Sienna Intermediate Shafts

Figure 4 – Kia Sedona Intermediate Shafts

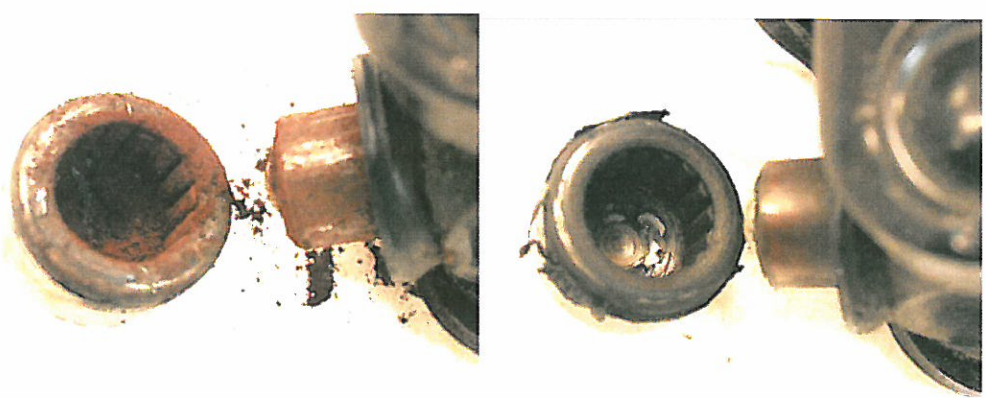

Figure 5 - Corroded Bearing (Left) and a Normally Wearing Bearing (Right)

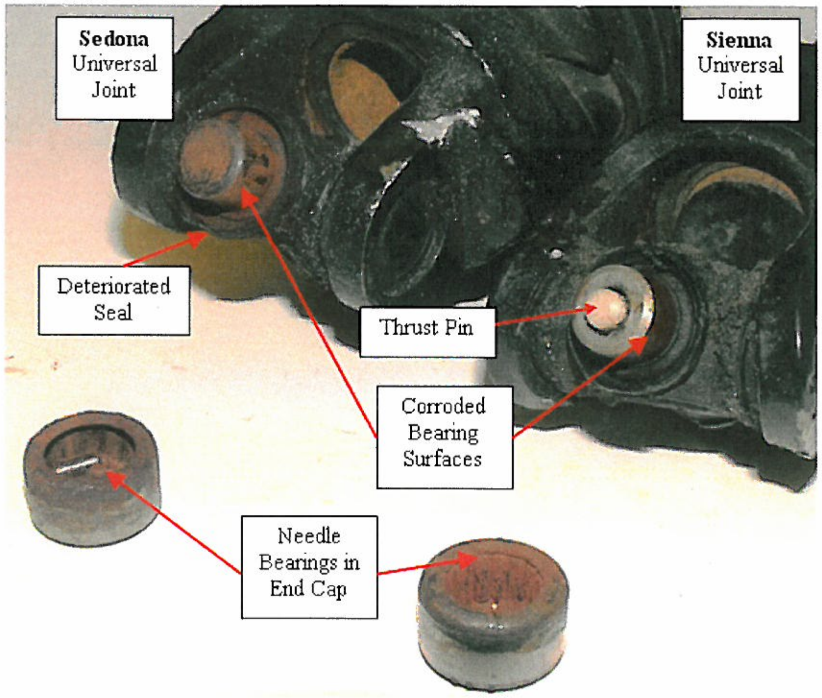

Figure 6 - Intermediate Shafts Disassembled, Sedona Left - Sienna Right

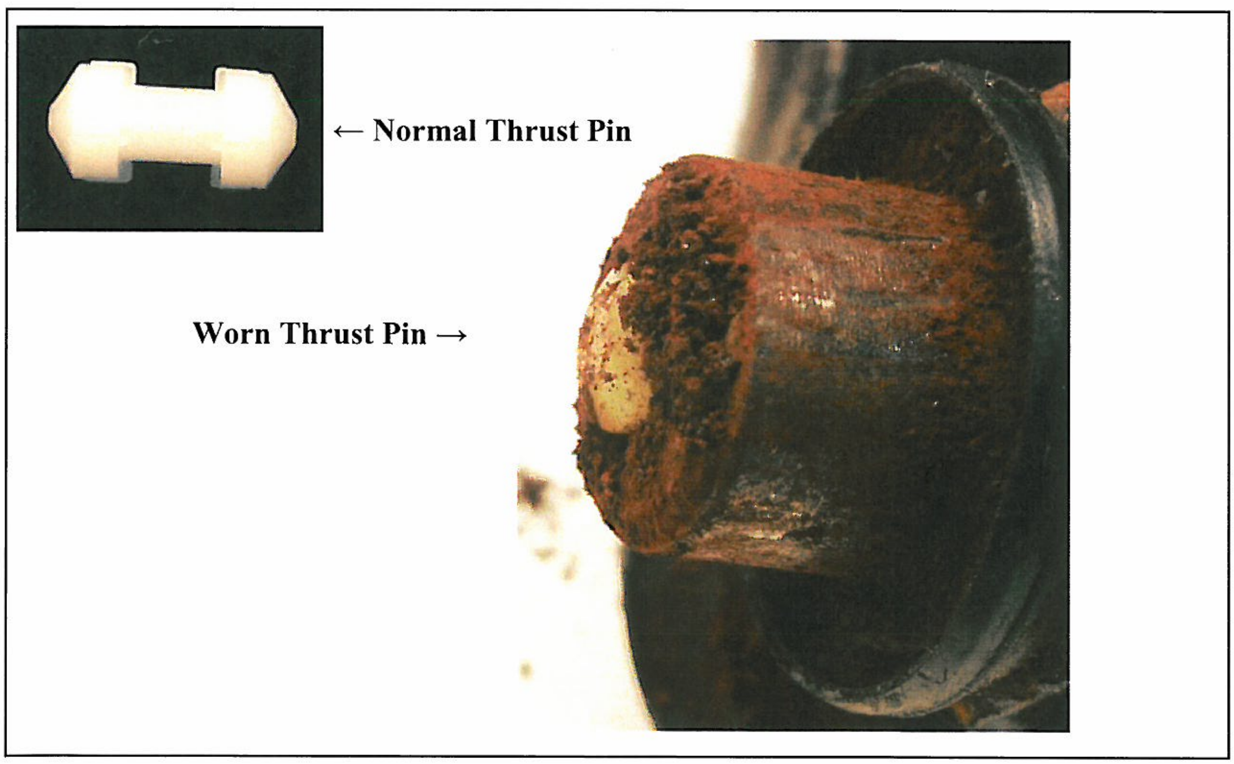

Figure 7– Sienna Worn Thrust Pin

5.2 Vehicle Testing

5.2.1 Suspended Static Steering Test – Both vehicles were instrumented with a data acquisition system that could monitor and record the following inputs: steering wheel angle, driver steering effort, vehicle yaw rate, and vehicle speed (Figure 8). It was found that the binding condition is most prevalent after the vehicle has been sitting dormant for an extended period of time. Once the wheel was rotated at least two times, the binding force was greatly reduced. Forces required to turn the steering wheel in a normally operated Sedona, measured in hand wheel pounds force, varied from one to three pounds (Figure 9). When a complaint shaft was tested, the required force varied from one to five pounds. With regard to the Sienna, a normally operating intermediate shaft required one to four pounds, while a defective intermediate shaft required one to eleven pounds (Figure 10). A sinusoidal pattern can be seen in the Toyota defective shaft as a result of only one of the two axes of the universal shaft corroding. The sinusoidal pattern is created because each axis rotates at a non-constant rate while articulated. During the highest rate of rotation, the bind becomes most evident.

Figure 8 - Data Acquisition System Installed in Kia Sedona

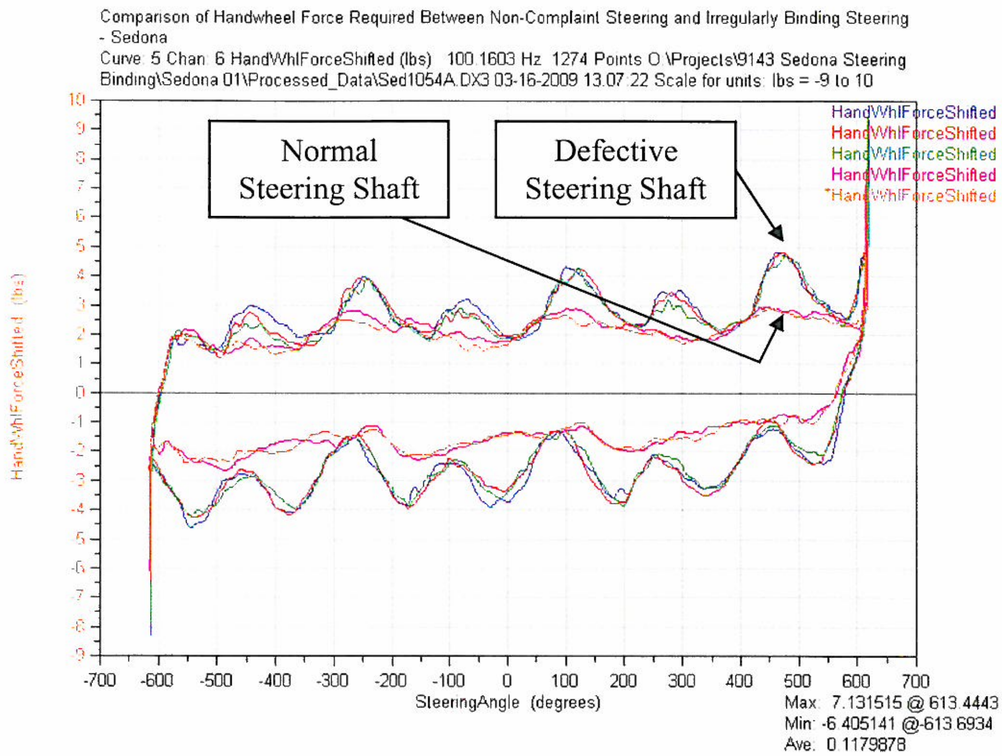

Figure 9 - Sedona Suspended Steering Test Normal versus Defective Intermediate Shaft

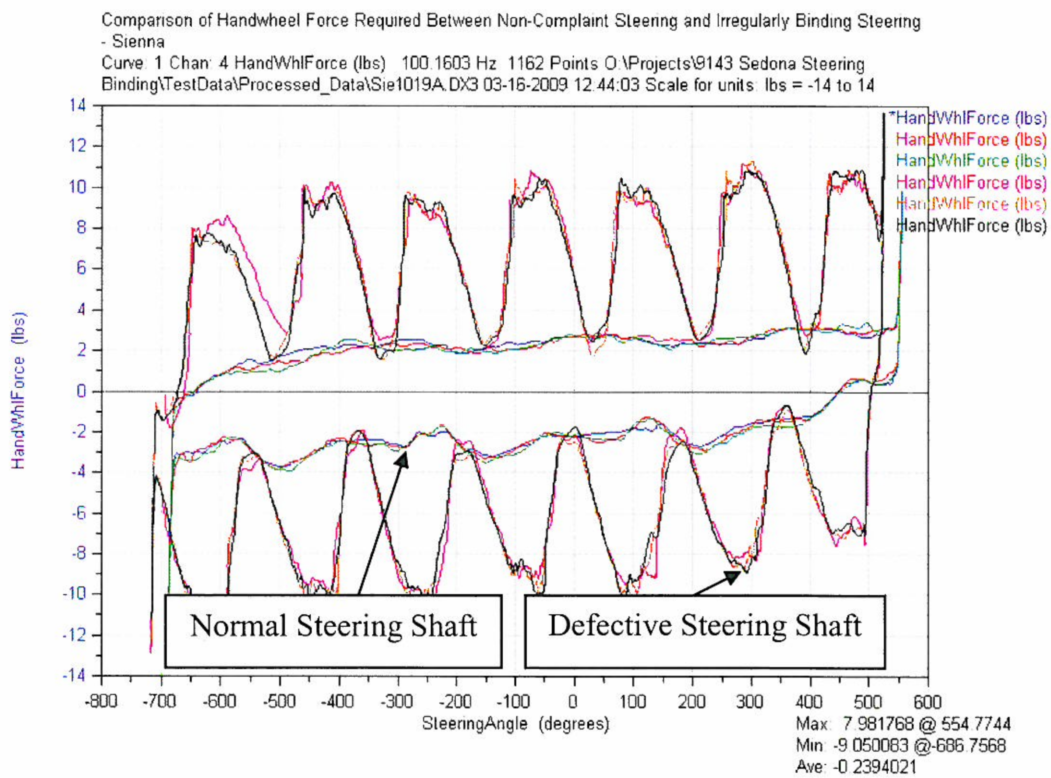

Figure 10- Sienna Suspended Steering Test Normal versus Defective Intermediate Shaft

5.2.2 Dynamic Steering Gain Test – Graphical representation of the steering forces can be seen in Figures 11 through 14. Figure 11 shows two traces of steering wheel forces required to generate increasing lateral acceleration in a Toyota Sienna with a non-defective steering shaft. The first trace (the more vertical of the two) is generated while the engine is running with normal power assist. The second trace is generated with the engine turned off to remove power assist. Figure 12 is the same test with a defective shaft installed in the Toyota Sienna. Figure 13 is also the same test but with the Kia Sedona and a non-defective steering shaft. Finally, Figure 14 is the same test with the Kia Sedona but a defective steering shaft.

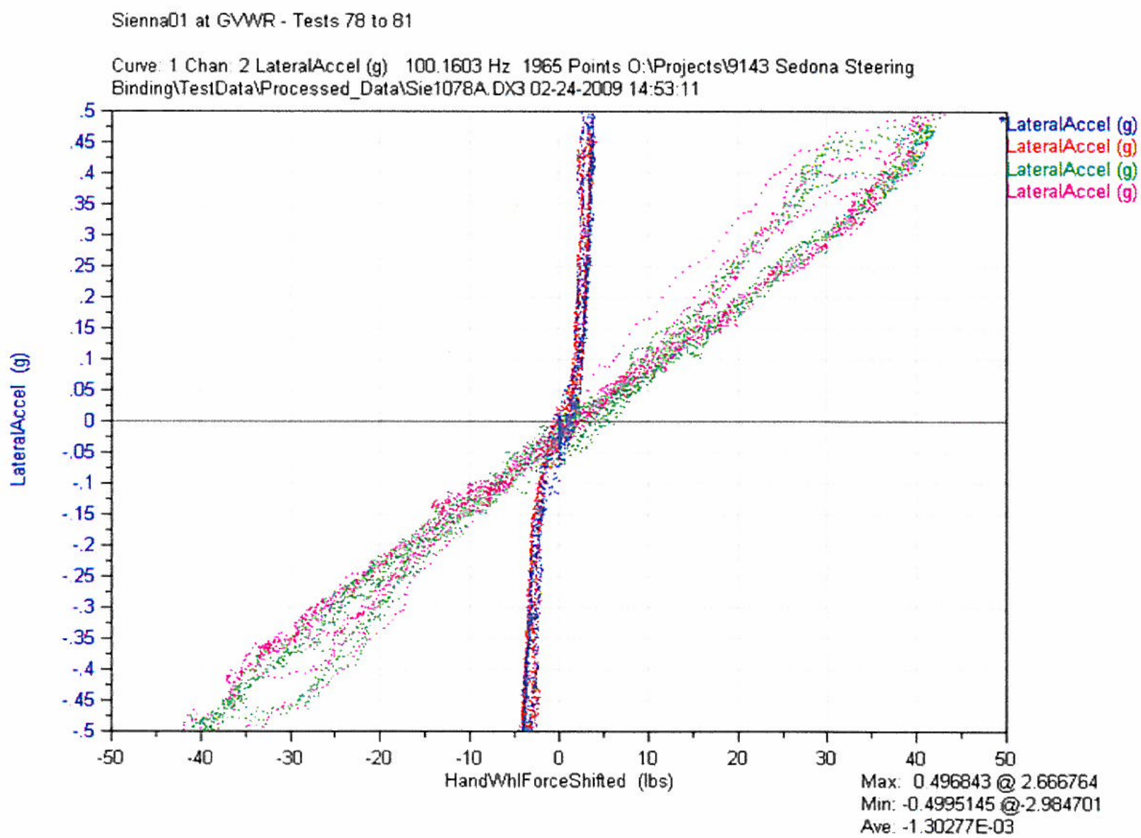

Figure 11- Sienna Steering Gain with Normally Operating Steering Shaft

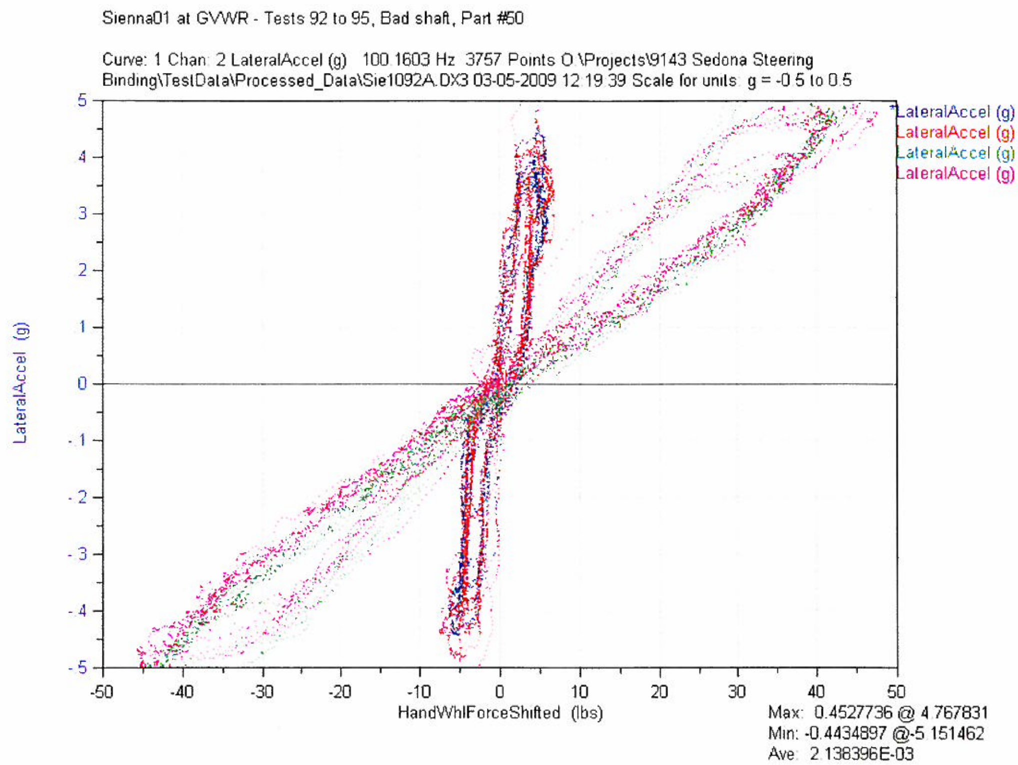

Figure 12- Sienna Steering Gain with Defective Steering Shaft

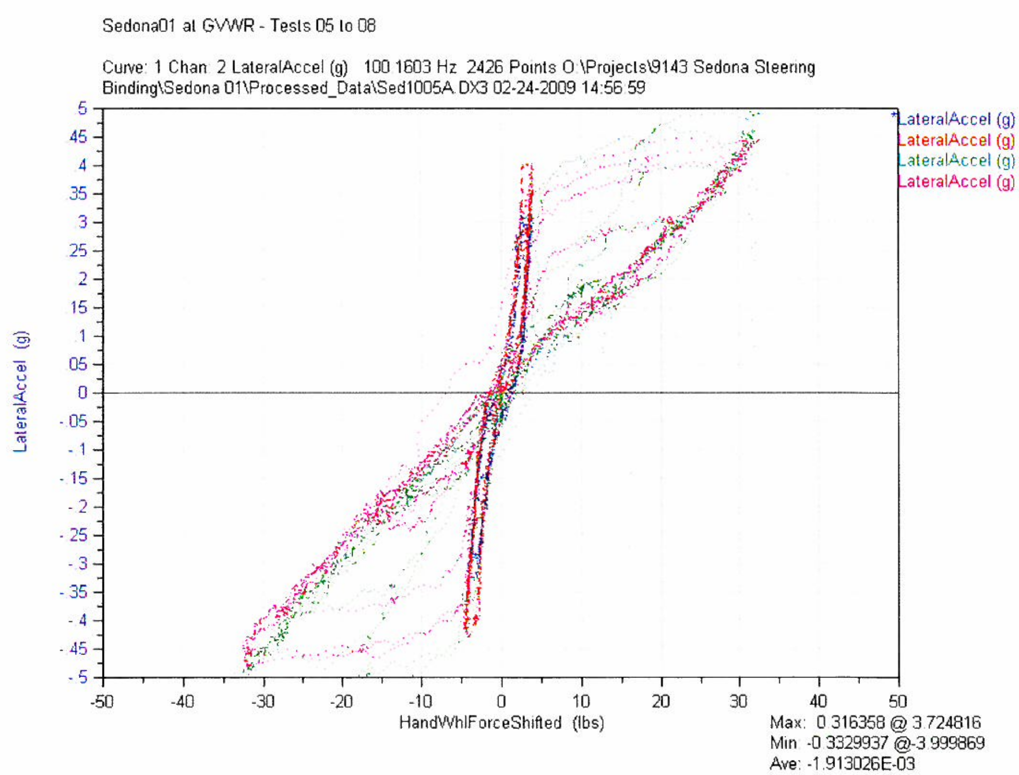

Figure 13- Sedona Steering Gain with Normally Operating Steering Shaft

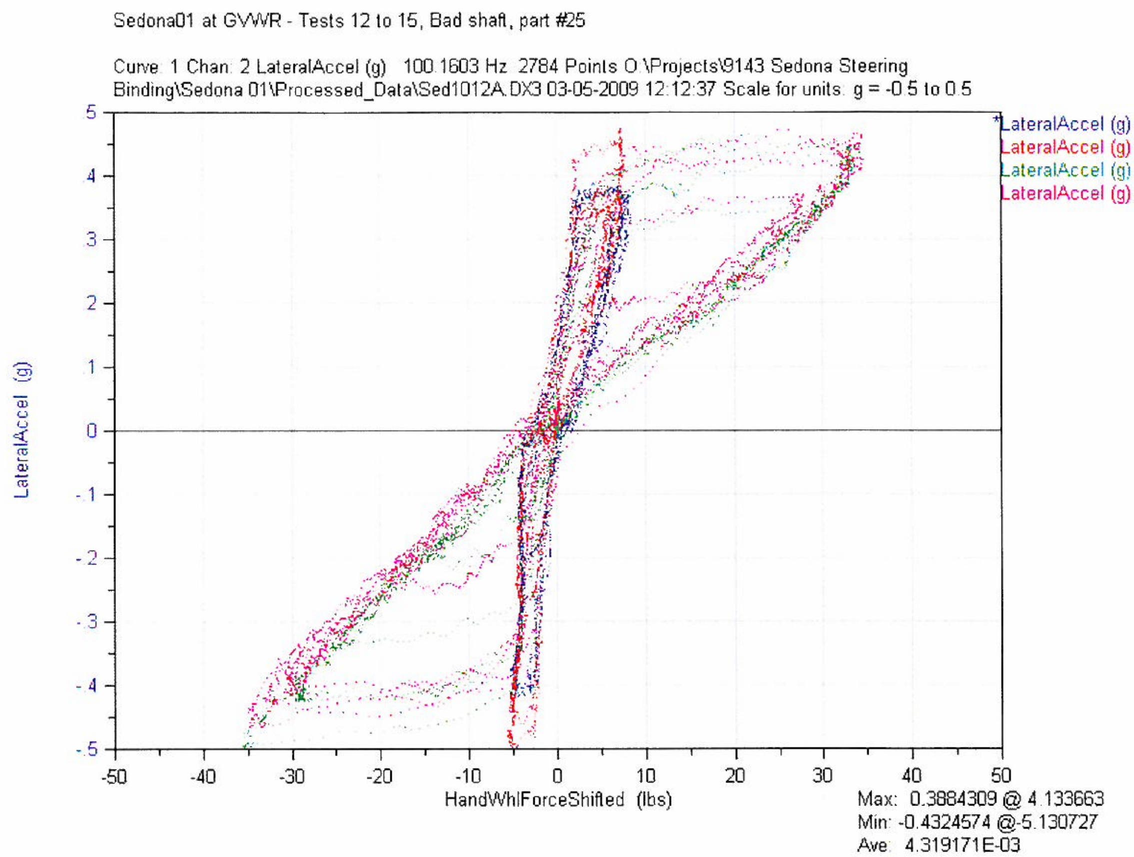

Figure 14- Sedona Steering Gain with Defective Steering Shaft

A summary of steering wheel pounds force required to achieve a given rate of lateral acceleration with both normally operating shafts and defective shafts is provided in Figure 15. For the Sedona, the most significant increase in steering force to produce a given lateral acceleration occurs during a 0.1 G maneuver. The result is an increase of 20% (6 divided by 5 pounds force) in steering effort. In the case of the Sienna, the most significant increase occurs during a 0.1 G maneuver. The result is a 9% (12 divided by 11 pounds force) increase in effort. During higher lateral acceleration maneuvers, the increase in effort resulting from a defective shaft becomes less evident.

Steering Gain Test Results				
	Tangential Hand wheel Force (lbs)			
	Sedona01		Sienna01	
Lateral Acceleration (g)	Good Shaft	Bad Shaft	Good Shaft	Bad Shaft
0.1	5	6	11	12
0.2	16	16	22	22
0.3	24	25	31	32
0.4	30	32	37	38

Figure 15 – Hand Wheel Force Required to Generate a Given Lateral Acceleration

6.0 – SUMMARY

Visual inspection confirmed that all submitted complaint intermediate shafts were experiencing a bind during rotational articulation caused by corrosion of the bearings in the universal joint. In suspended testing, the increase in steering effort associated with corroded bearing surfaces was noticeable, with the worst case requiring eleven pounds of force to turn. During the steering gain tests, there was also an increased rate of steering effort required to generate a corresponding lateral force. However, in all testing, the additional force required to steer a vehicle with the defective component was limited to a 20% increase or less.

The binding condition occurs gradually. Interviews with owners of complaint vehicles revealed that owners knew in advance of the deteriorating joint, and in some cases they had been experiencing the problem for almost a year.

APPENDIX A

List of Acronyms

NHTSA	National Highway Traffic Safety Administration
NVS	NHTSA Vehicle Safety
ODI	Office of Defects Investigations
TRC	Transportation Research Center, Inc.
VRTC	Vehicle Research and Test Center
SAE	Society of Automotive Engineers
GAWR	Gross Axle Weight Rating
GVWR	Gross Vehicle Weight Rating
LLVW	Lightly Loaded Vehicle Weight
G	Measure of acceleration, expressed as a ratio to gravitational acceleration