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Mr. William Longstreet
Federal Highway Administration
1200 New Jersey Ave., SE
Washington, DC 20590

Dear Mr. Longstreet:

I have attached the Task 2.1 and 2.2 report for FHWA Task Order No. DTFH61-10-D-00023/5005 "Inspection and Assessment of Crash Test Protocols". This document reports on our (1) inspection and assessment of Southwest Research Institute (SWRI) procedures for conducting an NCHRP 350 crash test and downloading/reducing data after a crash test, and (2) our evaluation of the capabilities of the SWRI lab staff to conduct crash testing under NCHRP 350.

Best regards,

A handwritten signature in black ink that reads "H. C. Gabler". The signature is cursive and includes a small flourish at the end.

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**Inspection and Assessment of Crash Test Protocols:
Task 2.1-2.2 Report**

Submitted to

Federal Highway Administration
U.S. Department of Transportation
Washington, DC

By

H. Clay Gabler, PhD
Virginia Tech
Blacksburg, VA

On

28 January 2015

Inspection and Assessment of Crash Test Protocols:

Task 2.1-2.2 Report

H. Clay Gabler, PhD
Virginia Tech
28 January 2015

Background

The goal of this project is to conduct a review of the crash test facility protocols and procedures of Southwest Research Institute (SWRI) to ensure that guardrail end terminal testing is conducted in accordance with NCHRP Report 350 criteria.

This report provides task summaries for the following two tasks:

- Task 2.1 Review SWRI Crash Test Procedures
- Task 2.2 Review SWRI Lab Staff Capabilities

Approach

On December 16-17, 2014, the PI visited the SWRI crash testing facility in San Antonio, Texas to inspect and assess the crash test procedures and protocols used to conduct crash tests to the NCHRP Report 350 procedures for Terminals and Crash Cushions. During this visit, the PI also witnessed two crash tests of the ET-Plus end terminal when tested to the NCHRP 350 crash test procedure. The results of the crash tests will be assessed once the complete test series has been completed in January 2014. The subject report is limited to assessment of the crash test procedures and protocols for conducting NCHRP 350 crash tests.

Our approach included inspection and assessment of the following:

- Procedures for documenting test vehicle parameters, including number and placement of data acquisition/recording devices. Data acquisition, including electronic data, video, and still photography, should meet or exceed that detailed in NCHRP Report 350.
- Procedures for constructing the test article and documenting as-built parameters.
- Procedures for calibrating data acquisition equipment.
- Procedures for conducting the crash testing within tolerances specified in NCHRP Report 350.
- SWRI's most recent ISO 17025 accreditation report

The inspection and assessment was conducted both by inspection of the documentation listed above, and by interview. Both the documentation and interview were provided by Ms. Jenny Ferren, SWRI manager of the Structural Dynamics and Product Assurance Division. Ms. Ferren was the director of the crash test series.

Task 2.1 Review SWRI Crash Test Procedures

The objective of this task was to inspect and assess SWRI procedures for conducting an NCHRP 350 crash test and downloading/reducing data after a crash test. As part of this subtask, SWRI provided the PI with copies of their crash testing test procedures, a copy of SWRI's most recent ISO 17025 accreditation report, and other documentation needed to make this assessment.

Review of Lab Certification

SWRI is certified to ISO 17025 for Calibration and Testing Labs, ISO 9001 for their Quality Management System, and is on the list of FHWA approved crash testing labs. All are excellent metrics of the quality of SWRI's crash testing protocols and procedures and SWRI's demonstrated proficiency in carrying out those crash testing procedures.

The SWRI crash testing facility has received ISO 17025 certification for conducting full scale crash tests. SWRI first received ISO 17025 certification in 2006 and has had this certification renewed annually. SWRI's current ISO 17025 is valid until 3/31/2016, but is renewed annually. The next annual visit will be conducted in March 2015. The scope for their certificate includes full scale vehicle crash testing under NCHRP 350 and MASH test procedures. The assessor for their ISO certification was the (American Association for Laboratory Accreditation (A2LA).

The ISO 17025 certification includes a very stringent review of personnel qualifications, equipment, and lab procedures by the ISO assessor, A2LA. A2LA first conducts a desktop review and then visits to observe and judge proficiency in carrying out these procedures. The certification visit includes review of videos, data sheets, and procedures. It should be noted that the only personnel changes since the last certification have been the addition of a technician (but he is supervised, i.e. is following instructions). Ms. Ferren said that they have had a very stable crew over the last few years. Several of the technicians have been at SWRI for over 20 years. The only recent change to SWRI's equipment has been the upgrade to digital video 3-4 years ago. Hence the ISO 17025 certification accurately describes the current SWRI procedures, equipment, and personnel.

The overall SWRI organization is also certified to ISO 9001. ISO 9001 is the quality management system certification which documents SWRI business procedures, and checks that SWRI follows those procedures. ISO 9001 is a quality management umbrella. ISO 17025 is under the umbrella of ISO 9001. ISO 17025 refers specifically to Calibration and Testing Labs.

Review of crash test procedures

SWRI maintains a comprehensive set of crash test procedures that are documented in the manual entitled "Crash Test Work Instructions. The crash test instructions book includes a section titled 'Process Traveler', a compilation of 11 checklists for pre-test prep, executing the test, and post-test tasks. The "Crash Test Work Instructions" also includes the following 5 sections with detailed step-by-step procedures on conducting the tests.

- Crash Test – Crash Test Procedures (Rev. 3) – approved 7/16/2014
- Crash Test – Test Article Installation and Vehicle Preparation (Rev. 4) – approved 7/17/2014

- Crash Test – Vehicle Steering and Propulsion (Rev. 4) – approved 7/17/2014
- Crash Test – Data Acquisition Instructions (Rev. 4) – approved 7/17/2014
- Crash Test – Documentation (Rev. 2) – approved 7/16/2014

To illustrate the detailed nature of these procedures, the contents of both the process traveler checklist and the crash test procedures are summarized below:

Process Traveler

The ‘Process Traveler’ leads off with a Step 1 section which summarizes the test conditions and a checklist that approvals have been received for the required NCHRP 350 data sheets. The Step 2 section contains a compilation of 11 checklists for pre-test prep, executing the test, and post-test tasks.

Step 2.1 is a checklist of pre-test documentation and prep of the test article including numbering of posts, stenciling of the end terminal, and a checklist of required pre-test photographs and short (5 sec videos) of the end terminal, each post, the downstream end termination, and photographs with tape measurement of the test article.

Step 2.2 is a checklist of pre-test documentation and prep of the test vehicle which includes application of external vehicle checkered dots/tape, test ID stenciling, photographs and short videos (5 sec) of the vehicle exterior, photographs of the vehicle interior showing location of the EDR, photographs of the vehicle interior showing steering, towing, and brake package, photos of the vehicle engine compartment, and photos of reference measurements of checkered dots/tape for later video analysis.

Step 2.3 is a pre-test checklist which photographically documents the position of the test vehicle against the test article, photos showing bumper height relative to the test article, and overhead photos/videos of the vehicle against the test article.

Step 2.4 is a pre-test setup checklist for the propulsion and steering system. Included are checkoff for layout of the steering and towing hardware, photos of the steering and towing hardware, checkoff for performance of the steering runs, verification of fuel level in the tow truck, and attachment of the towing mechanism to the tow truck.

Step 2.5 is a pre-test checklist for installation of test vehicle instrumentation, and includes check off for installation of the EDR unit, GoPro cameras inside vehicle, installation of the brake package in the vehicle, and impact sensors/flash bulbs.

Step 2.6 is a pre-test checklist for layout of the speed trap.

Step 2.7 is a pre-test checklist for layout of the high-speed cameras at specified locations (overhead, traffic side, downstream, opposite traffic side and traffic side zoom), and real-time cameras (panning, stationary, and drone).

Step 2.8 is a test execution checklist which includes a check that all pre-test prep has been completed. This step then checks the following: arming of the high-speed cameras, arming of the speed trap,

checking on the brakes, charging the flash bulbs, arming the EDR unit, activating the GoPro cameras, and activating the real-time cameras. The next step is to execute the test. The final step are immediate post-step steps including stopping the real-time cameras, stopping the GoPro cameras, downloading the EDR unit, turning off vehicle remote relay, downloading speed trap data, downloading high-speed videos, and performing the post-test documentation.

Step 2.9 is a post-test checklist for documentation of the test vehicle. Included in this step are photographs/videos of the vehicle from 8 angles, photos/videos of the vehicle exterior showing damage, photos/videos of the vehicle interior showing any intrusion, measurement of the final position and orientation of the test vehicle, and photos/videos of vehicle tire tracks showing trajectory.

Step 2.10 is a post-test checklist of documentation of the test article. Included are photos/videos of the end terminal from 8 angles and overhead, photos/videos of the end terminal showing the stamp number and test ID, photos/videos of each post, photos/videos of the downstream end termination, photos/videos of overall test article post-crash including the final position of the test vehicle, and a sketch of the test article showing damage and vehicle trajectory.

Step 2.11 is a final post-test checklist include removal of cameras, EDR, etc. from test article and test vehicle, and a final confirmation that all data from test has been saved.

Crash Test Procedures

The “Process Traveler” is followed by 5 sections which provide comprehensive procedures for conducting the tests. These work instructions are applicable to the overall ISO 9001:2000 quality management systems and the accredited testing under ISO 17025:2005. Each section was last updated, reviewed and approved in July 2014. All are summarized below:

- Crash Test – Crash Test Procedures. This procedure includes 7 pre-test preparation steps and 19 crash test steps typically performed the same day as the crash test.
- Crash Test – Test Article Installation and Vehicle Preparation. This section contains procedures for a) Test Article Installation including instructions to build the test article to customer-supplied drawings and/or specs including soil specifications, (b) test vehicle procurement, (c) vehicle preparation including installation of propulsion/steering/braking mechanisms, fixtures for data acquisition and on-board cameras, and measurements of pre-test mass and geometry. This section contains the standard geometry and mass measurement sheets required for NCHRP 350.
- Crash Test –Vehicle Steering and Propulsion. This section documents the typical procedures performed to steer and propel the test vehicle into the test article (end treatment in this case). This section describes the procedures for (a) laying out the desired vehicle trajectory (6 steps), (b) pre-test preparation of the vehicle propulsion system (7 steps), (c) pre-test preparation of the vehicle steering system (5 steps), and (d) pre-test testing of the tow and steering system (8 steps).

- Crash Test – Data Acquisition Instructions. This section provides procedures for conducting data acquisition during the test. This section describes procedures for (a) setup of the IST EDR unit using the IST DynaMax software (17 steps with screen shots), (b) instructions for downloading the IST EDR unit using the IST DynaMax software (10 steps), (c) instructions for processing the data downloaded from the IST EDR unit including converting the data from IST DynaMax format to Excel and inputting the data to the TRAP software for analysis (38 steps), (d) update of calibration files for the EDR (5 steps, only performed after a unit comes back from calibration), and (e) installation of updates of the IST DynaMax software (4 steps, performed as needed).

I noted that the test procedures refer to EDR4-M6 unit while the IST calibration data sheets refer to the EDR-4-6DOF-200/1200. Jenny Ferren assured me that the two are the same.

Not described in the crash test procedures were any protocols for use of the internal SWRI data analysis program. This custom SWRI program is used to double-check the results of the TRAP program. When asked about this, Jenny Ferren told me that the internal program is only used for spot checking the data, and only the TRAP results are reported.

- Crash Test –Test Documentation. This section describes the procedures to document the test. This section describes the procedures for (a) pre-test documentation including photos, videos, and measurements of the test configuration, test article, and the test vehicle. Note that these documentation requirements were part of the ‘Process Traveler’, (b) during-test documentation including high-speed and real-time video cameras, and (c) post-test documentation including post-test photos/videos of the test article, test vehicle, and associated damage to each. This would also include notes and measurements of post-test damage and any other measurements required by NCHRP 350.

Review of Data Acquisition and Data Reduction Methods

SWRI instruments the test vehicle with the IST EDR-4-6DOF-200/1200 data acquisition box (hereafter referred to as the EDR). Each EDR contains a data acquisition system. Each EDR also contains 3 embedded accelerometers and 3 Rate Gyros to measure and record both linear and angular accelerations along all three axes or orientation. The EDRs are calibrated by IST. Both EDRs were last calibrated in 2/2014. They must be recalibrated once per year. Jenny Ferren provided the most recent calibration certificates for both EDRs.

A single EDR, when properly installed at the center of gravity of the vehicle, and which properly records on all 6 channels will meet the vehicle instrumentation requirements of NCHRP 350. In the current test series, one concern is that SWRI is not instrumenting the vehicles with redundant instrumentation packages – which is a common safeguard against channel failure in a test. SWRI has 2 EDRs, and normally installs both to allow for redundancy. However, one of the EDRs is currently at IST for recalibration to ensure that it is ready for the January test series. Hence only one EDR was available for this test series.

The SWRI procedure is to download the data from each EDR immediately after a test. The data are then input to and processed by the TRAP software, a standard among FHWA crash test labs. SWRI also separately inputs the data to their own custom software and checks that the results duplicate the results output by the TRAP software. As an aside, the TRAP program is used in the FHWA Lab Interoperability Tests which FHWA uses to check that crash test data are being processed correctly. Ms. Ferren shared a copy of the 2013 FHWA Lab Interoperability report which showed SWRI results in comparison to other FHWA labs. These data download and reduction procedures are satisfactory for conducting and conducting NCHRP 350 crash tests.

Review of Procedures for constructing test article and documenting the as-built parameters of the test article.

SWRI procedures for constructing the ET-Plus plus guardrail system were summarized in the crash testing procedures presented earlier in this report. In addition, for this test series, SWRI developed a specialized data sheet for documenting the as-built dimensions of the test article. In both of the two crash tests on December 17 and 18, the PI observed the comprehensive set of dimensions which had been entered onto these sheets. My understanding is that the dimensions had been entered by SWRI personnel and selected values were verified independently by FHWA personnel.

Task 2.2 Review SWRI Lab Staff Capabilities

The objective of Task 2.2 was to evaluate the capabilities of the SWRI lab staff to conduct crash testing under NCHRP 350. Our approach was to evaluate the experience of both the lab management and the lab staff in conducting previous crash tests. The evaluation was based upon documentation provided by SWRI on their lab staff experience, and an interview of Ms. Jenny Ferren, the manager of the crash test facility.

My conclusion is that both the laboratory management and the laboratory staff are highly experienced in conducting full scale crash tests. Table 1 presents the years of experience and responsibilities for all of the SWRI crew who are conducting the crash test series. Ms. Jenny Ferren, the Manager of the Crash Test Facility has 14 year of experience and the Chief Test Engineer has 6 years of experience at SWRI. The experience of the crash test technicians ranges from 37 years to 4 years. Since the beginning of 2012, Jenny Ferren stated that SWRI has completed about 12 full scale crash tests. All were either NCHRP 350 or MASH tests. The Chief Test Engineer for the ET-Plus test series has been responsible for conducting a dozen crash tests.

Ms. Jenny L. Ferren is the director of the crash test facility, and serves as the Manager of the Structural Engineering Department in the Mechanical Engineering Division at SWRI. She hold a B.S. in Mechanical Engineering, from Texas A&M University (1995), and an M.B.A. from Texas A&M University - San Antonio (2013). Ms. Ferren joined Southwest Research Institute in 2001 as a Research Engineer in the Mechanical Engineering Division. She brought experience in both product design and mechanical testing from her previous employment at 3M, and has utilized those skills to conduct more than 500 successful structural and physical environmental test programs at SWRI for both commercial and government clients. As Manager of the Structural Dynamics and Product Assurance Section, Ms. Ferren is responsible for leading a team of engineers and technicians in evaluation, qualification, and reliability assessments of various systems and components for clients, and also supports qualification activities for many other SWRI Divisions. Ms. Ferren is responsible for business development efforts, including financial growth and promotional activities, and also serves as the System Administrator and Quality Manager for the Department's certified ISO Quality Management System. She has managed the crash test organization for the past five years.

The Chief Test Engineer for the ET-Plus crash tests series holds a MS in Mechanical Engineering, from Texas Tech University (2011) and B.S. in Mechanical Engineering, also from Texas Tech University (2006). He joined SWRI in June 2009 as an Engineer in the Structural Dynamics and Product Assurance (SDPA) Section. Since joining SWRI, he has supported the SDPA Section and Structural Engineering Department in several areas including mechanical system/structural design and analysis for dynamic environments, processing and analysis of dynamic response data, data acquisition and testing systems, destructive testing, and leading the dynamic impact (crash) testing program. In the last three years, the Chief Test Engineer has been responsible for performing more than a dozen full-scale crash tests.

Table 1. SWRI Crash Facility Personnel: Years of experience and responsibilities

Staff Position	Tenure	Responsibility
Jenny Ferren, Manager	14	Section Manager
		QMS System Administrator
		Administrative Project Manager
		Personnel assignments
		Report review
Chief Test Engineer	6	Chief Test Engineer
		HS camera setup
		HS camera trigger
		Data acquisition
		Data reduction
		Video processing
		Report generation
Research Assistant	37	Supervise barrier installation
		Vehicle prep
		Steering Setup
		HS Camera Trigger
		Towing cable setup
		DAQ installation
Staff Technician	33	Primary tow vehicle driver
		Vehicle prep
		Towing cable setup
		DAQ installation
Staff Technician	15	Secondary tow vehicle driver
		Vehicle prep
		Towing cable setup
		DAQ installation
		HS camera setup
Technician	4	Panning camera operator
		Test setup
		Vehicle prep
		Pre- and post-test measurements and photographs
Principal Engineer	19	Data acquisition support
		HS camera setup
Staff Engineer	38	Pre- and post-test measurements and photographs

Conclusions

The objectives of this report were to (1) inspect and assess SWRI procedures for conducting an NCHRP 350 crash test and downloading/reducing data after a crash test, and (2) to evaluate the capabilities of the SWRI lab staff to conduct crash testing under NCHRP 350. My conclusion is that SWRI's crash test procedures and personnel capabilities for conducting NCHRP 350 tests are excellent. Specifically,

- SWRI is certified to ISO 17025 for Calibration and Testing Labs, ISO 9001 for their Quality Management System, and is on the list of FHWA approved crash testing labs. All are excellent metrics of the quality of SWRI's crash testing protocols and procedures and SWRI's demonstrated proficiency in carrying out those crash testing procedures.
- SWRI maintains a comprehensive set of crash test procedures and crash test checklist for conducting a crash test to NCHRP 350 guidelines. In addition to my review, these procedures and the staff's proficiency in following these procedures were reviewed as part of SWRI's ISO 17025 certification.
- The SWRI data acquisition and data reduction methods are satisfactory for conducting and obtaining the parameters required by the NCHRP 350 test procedure.
- Both the SWRI laboratory management and the laboratory staff are highly experienced in conducting full scale crash tests. Ms. Jenny Ferren, the Manager of the Crash Test Facility has 14 years of experience and the Chief Test Engineer has 6 years of experience at SWRI. The experience of the crash test technicians ranges from 37 years to 4 years. Since the beginning of 2012, Jenny Ferren stated that SWRI has completed about 12 full scale crash tests. All were either NCHRP 350 or MASH tests. The Chief Test Engineer for the ET-Plus test series has been responsible for conducting a dozen crash tests.