



Full Vehicle Structural Durability Evaluation 4/5/6-Post Laboratory Vertical Road Simulation

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. The 4/5/6-Post Laboratory Vertical Road Simulation is used to evaluate structural durability performance of various vehicle subsystems using highly repeatable displacement profiles designed to represent proving ground road modules.

1.2 Applicability. This procedure can be used to develop or validate the structural durability of vehicle subsystems sensitive to vertical road input and powertrain torque reactions. Body subsystems where the body is mounted to a frame (e.g., pickup trucks, some vans and utility vehicles) can be validated using the 4/5/6-Post Test. Passenger car body and chassis subsystems and truck frame and chassis subsystems typically cannot be validated with this type of testing alone. This is due to the fact that non-vertical inputs contribute to significant fatigue damage in these types of subsystems. Non-vertical inputs cannot be reproduced on the 4-Post Test. Components sensitive to non-vertical road inputs will not experience an adequate level of correlation.

The tests referenced in this procedure do not provide a total vehicle durability test. No powertrain or electrical system operation is included. Degradation modes of rotating components such as wheel bearings are not accurately reproduced. Environmental factors such as elevated temperature, humidity and dust are not typically able to be included. Degradation modes related to exposure time are usually not accurately reproduced.

Additionally, some components are subject to unrealistic wear due to the accelerated nature of the test. Shock absorbers and some elastomers are known to wear prematurely during the test due to excess internal heat generation, which is not dissipated as in normal vehicle operation. Therefore, such components are usually monitored and replaced as necessary during the test. External cooling is usually applied to extend the life of some components during the test.

This procedure can be used for all passenger cars and trucks provided the hydraulic actuators are capable of reproducing the vehicle responses for the proving grounds being simulated. The source data to simulate the proving grounds can come from:

- Physical Road Load Data Acquisition (RLDA) (See GMW15019.)
- A virtual RLDA (vRLDA) or,
- Synthetic Road Drive Files (SynRoad).

Throughout the rest of this document, “desired response files” can be from any of these sources.

1.3 Remarks. This test procedure shall be performed according to the requirements stated in the Validation Plan or Activity Request.

1.3.1 The 4-Post Laboratory Vertical Road Simulation serves primarily to represent road-induced vertical loading applied through the four vehicle tires. These loads usually introduce fatigue, interference and wear phenomena to vehicle structures and sub-systems. See Appendix A for considerations in developing a Test Plan for a 4/5/6-Post Test. See Figure B1 in Appendix B for an example 4-Post setup.

1.3.1.1 The 5-Post and 6-Post designation refers to the addition of powertrain torque input and/or axle torque input to the existing four vertical tire inputs. These additional inputs are sometimes used to evaluate the powertrain mounting system and suspension attachments.

1.3.1.2 Depending on the GMW Durability Schedule selected, a 4/5/6-Post Laboratory Vertical Road Simulation can reproduce one test equivalent of fatigue exposure for most inertially induced vertical structural inputs in 100 h to 850 h.

1.3.1.3 For each vehicle, there is preparation time required before durability testing begins. This time may include gathering of desired response files, simulator drive file development, and correlation evaluation. These processes may take several weeks, and must be factored into the test plan. Less time is required if carryover or modified drive files can be used. This test procedure is written for laboratory test engineers and laboratory test technicians. This document is not intended to be used alone as a test specification. The simulation process is intended to produce laboratory road simulations for specific vehicle systems. That is, a set of drive files will closely reproduce measured responses from remote parameters and/or correlation transducers for one vehicle with a specific combination of ballast condition, ballast position, body stiffness distribution, and chassis components. If any of these characteristics are changed, the degree of laboratory-to-road correlation is compromised. However, the test requester and test engineer can together evaluate the risk entailed with a given compromise.

1.3.1.4 Experience has shown that the compromise is minimized under some conditions, such as a small change in shock absorber damping, mass change, and wheelbase change or body stiffness distribution. If the areas of interest are remote from the suspension-to-body interfaces, the risk can be further reduced. Significant time and cost reductions can be achieved by omitting or condensing the simulation process, if the risk is judged acceptable.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW3425	GMW15220 (ID)	GMW15232	GMW15244
GMW14048 (ID)	GMW15223	GMW15240	GMW15245
GMW15019 (ID)	GMW15224	GMW15242	GMW15268
GMW15219	GMW15226	GMW15243	GMW15269

(ID) = This standard is limited to internal distribution within General Motors and shall not be distributed outside this company. Contact the GM Lead Engineer for further instructions.

2.3 Additional References.

A supplier shall work with the responsible GM engineer to comprehend these requirements:

- CG190 GM Evaluation Report
- CG583 Development/Validation Test and Vehicle Review
- GMNA Structural Durability Laboratory (SDL) Electronic Log Book Web Page:
<https://gmweb.gm.com/sites/SDL/Pages/eLogbook.aspx>
- Program Specific Subsystem Technical Specification (SSTS)
- Program Specific Vehicle Technical Specifications (VTS)

3 Resources

3.1 Facilities. This test procedure assumes adequate physical testing facilities and infrastructure for 4/5/6-Post simulation are already in place, otherwise reference local procedure or process.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.2 Equipment. This test procedure assumes adequate physical equipment for 4/5/6-Post simulation is already in place, otherwise reference local procedure or process.

3.2.1 Wheel Restraint Fixtures. Wheel restraint fixtures should be used to help prevent the vehicle from leaving the simulator during the durability test. This may require the assistance of an experienced fixture designer. Specific examples are shown in Figure B2 and Figure B3, Appendix B.

Note: Some regional laboratories may use restraints, which are mounted to the wheel pads on the hydraulic actuators. These restraints do not physically attach to the wheels.

3.2.2 Engine Torque and/or Rear Axle Torque Input Fixture. If engine or rear axle torque input will be simulated, fixturing to attach the torque input device to the engine/transmission will need to be designed and fabricated. Reference GMW15220.

3.2.3 Simulated Battery Mass. The battery(ies) may be removed from the vehicle prior to installation on the test rig to prevent battery acid spillage. If an appropriate simulated battery mass does not already exist a new one must be designed and built.

Note: Some laboratories allow the use of live batteries or batteries with water instead of acid.

3.2.4 Steering Gear Lock-out. The steering gear must be locked to prevent the front wheels from turning during the test. If an appropriate steering gear lock-out fixture does not already exist, a new one must be designed and built.

Note: Regional laboratories using wheel restraints mounted on the actuator pads may not lock the steering gear as the restraints keep the wheels from turning.

3.2.5 Ballast Box(s). Cargo carrying vehicles typically have wooden ballast boxes installed to prevent steel shot bag ballast from shifting during testing.

3.2.6 Ballast.

3.2.6.1 Water torso bottles to simulate passenger weight on seats (70 kg per bottle is standard). See Figure B4 in Appendix B.

3.2.6.2 Steel shot bags to simulate cargo ballast in rear cargo areas, trunks, pickup boxes or roof rack carriers (11 kg per bag is typical). See Figure B5 in Appendix B.

3.2.6.3 Solvent to replace fuel in fuel tank (typically fill tank to 75% full for trucks and 90% full for cars). Reference GMW15240 for instructions on Flushing and Ballasting Fuel Systems.

3.2.7 Safety Restraints. If additional safety restraints are needed as backup to the wheel restraint system, avoid attaching the safety cables to the vehicle in a manner that will damage the vehicle during the durability test.

3.3 Test Vehicle/Test Piece.

3.3.1 Test Specimens.

3.3.1.1 Specimen Overview. Each test specimen will have the following characteristics:

3.3.1.1.1 Operational suspension with representative components.

3.3.1.1.2 Option content and vehicle ballast as needed to meet project goals defined by the requester (see A1.5).

3.3.1.1.3 Appropriate dimensional characteristics (i.e., proper body panel fit and alignment, correct trim height adjustments, closures properly adjusted, etc.)

3.3.1.2 Operational Powertrain. An operational powertrain is usually not required in the test specimen, but is needed for a physical RLDA vehicle if used. The powertrain used in each test specimen must include representative mass and mounts.

3.4 Test Time.

Calendar time:	15 d to 50 d
Test hours:	100 h to 850 h
Coordination hours:	20 h to 100 h

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. The project team should include members who perform the following roles. A single person may perform several roles at some test sites.

3.6.1 Test Engineer. It is recommended that this role be staffed by a person with previous road simulation experience.

3.6.1.1 Formulate Test Plan. After the simulation laboratory has received a test request, a test engineer will be assigned to the project. The test engineer will investigate the options and champion the test plan. The engineer should review each activity with the supplier of that activity and agree on the requirements. The timing requirements of all activities should be the commitments of the suppliers as partners on the project team.

3.6.1.2 Test Site Documentation. The test engineer and test technician are responsible to keep a test site logbook in which all test information is recorded. For example, refer to the GMNA Structural Durability Laboratory (SDL) Electronic Log Book Web Page (<https://gmweb.gm.com/sites/SDL/Pages/eLogbook.aspx>) for the contents of the durability test log book (see Table of Contents).

Also, the test site logbook must be updated with any maintenance operations or changes made to the test rig or test specimen during the course of the project.

3.6.1.3 Test Issue Documentation. The test engineer is responsible for documenting test issues that result in non-conformance to performance requirements via the approved electronic system: Problem Resolution Tracking System (PRTS+).

3.6.1.4 Prepare Data. The test engineer is responsible for performing data integrity checks, data editing, etc., as needed based on the source data for the desired response files and/or re-used drive files. A thorough understanding of the Remote Parameter Control (RPC) (or equivalent) process, pseudo-energy and fatigue theory is a requirement.

3.6.2 Test Requester.

3.6.2.1 Provide Test Material. The test requester must provide an operational RLDA/test development vehicle containing components of a level consistent with the project plan. If existing desired response file or drive files can be used, a RLDA/test development vehicle may not be required.

3.6.2.2 Approve Vehicle Content. The test requester must sign off on each test vehicle's content using corporate form CG583 (Development/Validation Test and Vehicle Review). This is accomplished by their visual inspection of the test vehicle's content. It includes identifying information (such as part numbers) and measured engineering properties for key components.

3.6.2.3 Approve Correlation Parameters and Transducer Locations (if Required). The test requester may be asked to help select and approve meaningful correlation transducer locations.

3.6.2.4 React to Durability Observations. The test requester must provide the project team with direction regarding each observation. There is usually some leeway regarding when and if the damage from an observation should be repaired. The project team should recommend a course of action, but the requesting organization must agree before work proceeds.

3.6.3 Fixture Designer (Optional). A Test Fixture Designer may be responsible for designing test fixtures and keeping a database of historical designs.

3.6.4 Test Technician. It is recommended that this role be staffed by a person with previous road simulation experience.

3.6.4.1 Instrumentation. The test technician is responsible for installing and calibrating all instrumentation on the vehicle.

3.6.4.2 Maintain Hydraulic Equipment. The technician is responsible for maintaining all of the hydraulic equipment at the test site.

3.6.4.3 Perform RPC (or equivalent) Iterations. The test technician (and/or test engineer) is responsible for simulator drive file development.

3.6.4.4 Test Monitoring. The test technician (and/or test engineer) is responsible for monitoring the test specimen and keeping a log of the test observations.

4 Procedure

4.1 Preparation. The desired response file are obtained from one of the sources mentioned in 1.2: Physical RLDA, a virtual RLDA (vRLDA) or Synthetic Road Drive Files (SynRoad). Note that the remote parameter being iterated to may change depending on the source of the data.

An example Simulation Checklist has been created in the GMNA SDL Electronic Logbook for things that need to be done to the test property(ies).

4.1.1 Edit RLDA Data.

4.1.1.1 Verify Data. Before data is edited, it should be verified. This means that the data should be checked to assure that there are no sections that exceed full-scale values or contain unwanted noise or spikes. The channel description and units should also be consistent for every data file. Initial data verification is typically done by the engineer performing the measurements at the proving grounds. Additional data verification should be done by

the lab test engineer after data has been transferred and placed in the standard directory structure. Refer to GMW15243 for initial data preparation requirements.

4.1.1.2 Calculate the Editing Baseline. The editing baseline represents the overall energy of the wheel spindle acceleration data for the unedited data (or fatigue damage for correlation parameters if used). The baseline for a given channel represents the sum of the calculated energy from each road module multiplied by the repetitions specified in the road durability test procedure. Refer to GMW15244 for the details of the calculation.

4.1.1.3 Eliminate Modules. If a module represents less than 1% of the calculated energy for the overall test across all channels, and that module does not encompass a near peak event (> 90% of the overall peak) on any channel, it is typically eliminated from the laboratory durability test. Therefore, it need not be included in further editing steps. Do not eliminate transient events such as potholes based on energy calculations. Any other module that is not achievable on the road simulator would also be eliminated from the editing process. Typically, the content of low frequency twist and driveway modules is substituted into the durability test with synthetic drive files.

Events not run on the 4/5/6-Post simulator include rail shipping and haul-away simulations, braking and cornering events, city and high-speed events, and adverse environment exposure.

4.1.1.4 Data Editing Philosophies. A major reason for running vehicle simulation tests is to accelerate durability testing. This necessitates meeting several conflicting objectives:

- Reduced test time.
- Sufficient test severity.
- Physically realizable and realistic on the road simulator.
- Accurate reproduction of the road modules selected.

Reference GMW15232 for a Generic Data Flow Process.

4.1.1.5 Data editing to meet these objectives is accomplished by removing less severe sections of data from the road response data files that will be reproduced on the laboratory durability test. Test severity is quantified by energy calculations. It is evaluated by comparing the energy retained in the edited data with that calculated from the unedited road data. Refer to GMW15244 for a description of the energy editing process.

4.1.1.6 The target test duration may be expressed as one of the goals of the test development (A1.2). Therefore, both the test duration and retained energy must be considered when evaluating the success of an editing pass.

4.1.1.7 There are two general approaches to data editing: graphic and bulk.

4.1.1.8 In the graphic method, the RLDA time history data is visually reviewed to determine where non-damaging segments of data can be removed. This method is used for road modules containing a few easily identifiable non-damaging sections. An example would be the leading and trailing portions of a Pothole file where the approach and exit is in the data, but is not necessary for the test. The graphic editing method for pothole modules is presented in GMW15224.

4.1.1.9 In the bulk method, a computer program is used to compare data statistic(s) with user-defined thresholds to determine whether to keep or discard a segment of the data.

There are some common pitfalls to all editing techniques. For example, tapers between edited frames of data can produce undetectable anomalies in the desired response that are not physically realizable on the road simulator. These motions adversely affect test correlation. Therefore, highly dynamic data, such as that found during the Belgian Blocks, should be edited sparingly if at all.

Editing steps should be documented according to the guidelines described in 5.3.2.

4.1.1.10 Identify Files for Bulk and Graphic Editing. Belgian Blocks, Truck Belgian Blocks, Potholes, and Truck Severe Trough modules should not be bulk edited. Rather, they should be graphically edited to remove leading and trailing zeroes. Do not remove the low energy segment in the middle of the Belgian Blocks modules (approximately 10 s) because this may cause the vehicle to go out of phase. Keep at least 10 s (or 2 frames) of data for the potholes and truck trough. This 2 frame minimum requirement is dictated by the RPC iteration process. All other road modules can be bulk edited.

4.1.1.11 Perform Graphic Editing. When editing a transient event, it is recommended to keep a minimum of 2.0 s before and 2.0 s after each event. The event must be reasonably centered in this window to prevent tapering routines from creating unrealistic desired responses. Refer to GMW15224. Make sure at least 2 frames of data remain after editing.

4.1.1.12 Execute Bulk Editing. Bulk editing is a tool used to reduce the length of files and retain most of the energy and/or fatigue damage. The bulk editing tool allows the operator to specify a statistical threshold value for which windows of data are either retained or removed.

Windows of data are removed from each file based on statistical thresholds such as variance, maximum, minimum and/or root mean square (RMS). For 4-Post Tests, wheel spindle acceleration channels are typically bulk edited to eliminate any window of data that has a variance value less than the weighted average variance for that channel. To eliminate a window of data, all channels must have variance values less than the weighted average variance simultaneously. Otherwise, the window of data is retained.

4.1.1.13 If using this criterion for bulk editing results in a test duration that is longer than required, a value some percentage higher than the weighted average value (120% for instance) can be used. Using a higher value will result in more windows of data being eliminated, and thus, shorter test duration. However, using a higher value will eliminate some windows of data that contribute to the overall energy or fatigue damage. This will result in the test having less than 100% of the energy retained. This condition can be rectified by increasing the file repetitions to bring the energy value back up to the baseline energy. This process of increasing file repetitions to make up for missing energy is done by a uniform percentage for all files except the transient events and low frequency twist events (which typically do not have repetitions adjusted).

Note: Do not increase file repetitions by more than 110% of the original repetitions, as the load distribution may be significantly altered.

Although the process is highly automated, it is recommended that the user(s) allow time to review comparative data statistics, energy and/or fatigue damage comparisons, frequency content via power spectral density plots, and time history plots after bulk editing. Refer to GMW15269 for procedure details.

4.1.1.14 Editing Considerations for 5/6-Post Tests. Powertrain torque and axle torque channels are not typically used for editing purposes. The torque channels are carried along with any window of data that is retained as a result of editing based on the vertical acceleration channels. This does not preclude editing based on torque input when it is deemed necessary.

4.1.2 Calculate Summaries of Editing Results.

4.1.2.1 Calculate retained energy and/or fatigue damage for the edited data sets. Repeat the procedure from 4.1.1.8 to calculate energy and/or fatigue damage in the edited data (GMW15244). Use the same input parameters that were used in the baseline calculations (i.e., scale factor, notch factor, material properties, and bin size). Fatigue damage for all events to be used during the laboratory durability test should be included. Create an energy retention summary and/or fatigue damage retention summary comparing the edited to the unedited files.

4.1.2.2 Calculate Test Duration. Determine the time retained from each edited road module, multiply by the repetition factors, and sum the results.

4.1.3 Evaluate Results of Editing.

4.1.3.1 Review retained energy or fatigue damage. Compare edited retained energy and/or fatigue damage with the baseline (unfiltered) energy and/or fatigue damage. As a guideline, the retained fatigue damage should be at least 90% of the baseline for each correlation parameter evaluated. If retained energy is the only criterion being evaluated, the reduction in energy is typically corrected by increasing the road repeats to get the retained energy back to 100%. Do not adjust transient event and synthetic event repeats.

4.1.3.2 Review Resulting Test Duration. A typical runtime of 17 h per day (out of 24 h) is assumed to account for downtime due to inspections, observation resolution and fixture maintenance. This value should be compared to the test duration goal set in A1.2.

4.1.3.3 Corrective Actions if Goals are Not Met. If editing goals are not met, review modules to eliminate and repeat bulk editing. One way to select road modules to further modify is to rank them based on "fatigue damage density", or fatigue damage per module divided by the time required to run the module. Modules that are repeated many times are also good candidates for further editing.

Another technique to improve damage retention and/or reduce test time is to perform a multiplier optimization on the drive files. For details on this technique, reference local procedure or process.

Note: Do not increase file repetitions by more than 110% of the original repetitions, as the load distribution may be significantly altered.

4.1.4 Prepare for Test Development.

4.1.4.1 Prepare Test Site. Refer to 4.1.17.

4.1.4.2 Prepare Development Specimen. Refer to 4.1.17.

4.1.4.3 Install test development vehicle on the test rig using approved fixtures and safety devices.

4.1.4.4 Reference local procedure or process for operation instructions for the Nitrogen Static Lift system if required.

4.1.5 Measure Test System Response. Frequency Response Function (FRF). The FRF is the math model that characterizes remote parameter transducer responses to the servo-hydraulic drive signals across a range of frequencies. The inverse of the FRF is used to predict the motion of the hydraulic cylinders required to reproduce the remote parameter transducer responses from the road on the test development vehicle. The system characterized by the FRF includes the test fixture, servo-hydraulics, the test development vehicle, transducers, and the data acquisition system.

4.1.5.1 Measure Remote Parameter Responses and Calculate FRF. Excite the test rig and vehicle with command signals containing frequencies and amplitudes in the range that is expected to test. (The typical frequency range is between 0.4 Hz and 40 Hz, depending on the types of transducers being used, vehicle dynamic response, and the interaction with the hydraulic actuator dynamic characteristics and the constraints.) Details of the procedure should reference local procedure or process.

4.1.5.2 Interpret FRF. The system FRF should be examined to determine if it makes physical sense. This requires that the examiner have some knowledge of the physical attributes of the system. A FRF cannot be successfully interpreted without assistance from experienced users. The following characteristics are among those that should be checked. This list is not comprehensive.

- Diagonal nature of the FRF, including diagonal sub-matrices.
- Static checks.
- Dynamic checks.
- Antinodes.
- Determinants and singularity.
- Phase noise.
- Nodes.

For a more detailed description of FRF reference local procedure or process.

4.1.5.3 Calculate Coherence Between Drives and RPC (or Equivalent) Responses. Coherence provides a measure of the degree to which an output may be described as the linear combination of the inputs, expressed in the frequency domain. Two types of coherence are available. Multiple coherence indicates the degree to which a response channel can be attributed to a combination of all the input channels. Partial coherence indicates what portion of a given response channel is due to a specific input channel. Both types of coherence range between 0 and 1 for each frequency band. A value of 1.0 indicates perfect linearity between the input and response channels. Lower values indicate the presence of measurement noise, system non-linear characteristics, and absent inputs that may or may not need to be addressed. Interpretation of coherence is described in GMW15223.

4.1.5.4 Apply Filters and Band Limits. A 4/5/6-Post simulator is limited by actuator displacement in its ability to reproduce low frequency events (below about 0.4 Hz). Actuator limitations above 40 Hz make test rig responses uncontrollable at those frequencies. Filters are used to remove those frequencies from both drive and desired response file and from the FRF. Additionally, the body/frame acceleration data is used to control the low frequency body modes (bounce, pitch and roll) over a narrow frequency band. Specific notch filters are used for both the spindle/axle and body/frame acceleration channels to allow for this mode control. The following filter criteria works for most vehicles:

4.1.5.4.1 Filter the spindle/axle acceleration channels to remove or zero the band from the first two spectral lines (0.0 Hz to 0.4 Hz for 409.6 Hz sample rate/2048 points per frame, 0.0 Hz to 0.5 Hz for 512 sample rate/2048 points per frame), from 1.4 Hz to 1.8 Hz (1 spectral line to either side of 1.6 Hz), and 40.0 Hz to maximum frequency.

4.1.5.4.2 Filter the body/frame acceleration channels to remove or zero the band from 0.0 Hz to 0.8 Hz and 2.4 Hz to maximum frequency (sample rate of 409.6 Hz, or 0.0 Hz to 0.75 Hz and 2.5 Hz to maximum frequency for 512 Hz sample rate).