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Managing Water in the West

Dynamic and Static Testing of Vehicles as Anchors

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Drop weight testing using a simulated vehicle as an anchor was performed in a laboratory environment. The test mass and test lanyard elongation were modeled after American National Standards Institute (ANSI) standards.

Lab testing showed that a simulated test vehicle with a weight of 4,675 pounds (lb) began to slide at 2,233 lb of static load whereas a similar field test vehicle slid at 3,200 lb. Removing weight from the rear portion of the vehicle reduced the required static force needed for sliding; however, the maximum dynamic force remained fairly consistent while the vehicle slid for a greater distance (up to 7 inches at 2,221 lb of maximum force).

None of the laboratory tests met ANSI Z359.18 (2017) or ANSI Z359.6 (2016) standards, as the 4,675-lb test vehicle slid an average of less than 1 inch but failed the static load requirements imposed by both standards. Static testing appears to have a more stringent requirement. Static testing to 5,000 lb would satisfy both ANSI standards without having to perform drop testing.

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BUREAU OF RECLAMATION
Research and Development Office
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Final Report ST-2018-0006-01

Dynamic and Static Testing of Vehicles as Anchors

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ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
C.G.	center of gravity
EIPS	extra improved plowed steel
GVWR	gross vehicle weight rating
lab	laboratory
lb	pound(s)
lbf	pounds force
MAF	maximum arresting force
OSHA	Occupational Safety and Health Administration
psi	pounds per square inch
Reclamation	Bureau of Reclamation
SPRAT	Society of Professional Rope Access Technicians

Symbols

”	inch(es)
#	number
%	percent

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EXECUTIVE SUMMARY

Drop weight testing was performed using a simulated vehicle as an anchor in an experiment, which was modelled after Z359.18 – "Safety Requirements for Anchorage Connectors for Active Fall Protection Systems." Although the methods outlined by American National Standards Institute (ANSI) Z359.18 were followed, the dynamic test failed to produce a peak load close to the expected 5,000 pounds (lb) either at the drop weight or at the vehicle. This was the case whether the vehicle slid or remained stationary.

The goal of this study was to compare results between static and dynamic testing as well as between laboratory (lab) testing and previous Bureau of Reclamation field testing of vehicle anchors. Lab testing showed that the simulated test vehicle with a weight of 4,675 lb began to slide at 2,233 lb of static load whereas a similar field test vehicle slid at 3,200 lb. Removing weight from the rear portion of the vehicle reduced the required static force needed for sliding; however, the maximum dynamic force remained fairly consistent while the vehicle slid for a greater distance (up to 7 inches at 2,221 lb of maximum force).

None of the lab tests met ANSI Z359.18 requirements for Type D anchors, which require that the anchor be capable of supporting the greater of 2,700 lb or 1.5 times the maximum arrest load measured at the anchor (which varied in this test from 3,245 to 3,332 lb). Likewise, the test setups did not meet ANSI Z359.6, which would require 3,600 lb static load support to meet a typical maximum fall arrest requirement of 1,800 lb. Since the 4,675-lb test vehicle slid an average of less than 1 inch but failed the static load requirements imposed by both ANSI standards, static testing appears to be have a more stringent requirement. Static testing is also easier and more straightforward to test with less potential variability introduced from a rigging system. Testing performed to satisfy the 3,600-lb static strength anchor requirement of ANSI Z359.6 (2016) or to 5,000 lb, would satisfy both ANSI standards without having to perform drop testing.

BACKGROUND

The Bureau of Reclamation (Reclamation) has been using different forms of rope access since early in the agency's history. For decades, wire-cored manila ropes and boatswain's chairs were the accepted equipment that allowed workers to access otherwise inaccessible parts of Reclamation structures. Installed anchors were usually 1-1/2" schedule 40 steel pipe installed in a hole that was usually drilled with a pneumatic impact drill. Occasionally, drill steel itself was used, but due to its tendency to become brittle and crystallize, it was frowned upon for use as a safe anchor for most Reclamation work. Two anchors were usually required, and a 7/8" diameter rope was secured to the anchors with clove hitches.

As Reclamation transitioned to modern rope access techniques in the late 1990s, the need for safe, reliable anchors became more critical than ever. In June 2013, Reclamation's Technical Service Center published Technical Memorandum No. MERL-2013-29 titled, Rope Access Anchors: Research and Testing of Concrete Anchor Bolts. In this report, concrete anchor bolts (also typically used in natural rock) were evaluated and tested specifically for rope access and fall protection anchors. The following is an excerpt from the Executive Summary of that report:

Reclamation's Technical Service Center has tested life safety anchors to continue to develop safe practices and protocols for rope access maintenance and inspection of inaccessible features on Reclamation structures. The objectives are stated as follows:

1. *Determine if and how Reclamation should test and evaluate existing anchor installations. Proof testing has been used infrequently to test anchor worthiness in the field, but will repeated proof testing weaken the anchors? What level of proof testing is appropriate to gauge fitness for service?*

2. *Determine the most effective anchors to be utilized for fall protection/rope access under common loading situations.*

3. *Determine and evaluate the effects that any potential installation defects may have on anchor strength.*

4. *Evaluate the effect of concrete strength on anchor strength.*

5. *Evaluate the effect of loading condition on anchor strength. It may be necessary to stock and use several types of anchors depending on the situation.*

Concrete slabs were placed during the summer of 2011, and testing was completed in August 2012. Multiple anchor systems were evaluated, and the variables included concrete strength, loading condition, and installation methodology. Many of the anchor configurations are not strong enough to meet the 5,000 pound (lb) load requirement specified by the Occupational Safety and Health Administration (OSHA) and the Society of Professional Rope Access Technicians (SPRAT) guidelines; these anchors are highlighted in red in Tables 4 and 5. When utilizing these configurations, anchors should always be used in at least load sharing pairs. Although an anchor meets the 5,000 lb requirement, the failure mechanism may provide an added measure of safety if it fails gradually by pulling out instead of failing catastrophically (i.e., bolt fracture). Glue-in threaded rod anchors appear to be susceptible to weakening during repeated proof loading cycles. It is possible that this type of loading scenario could adversely affect additional anchor systems that were not evaluated for fatigue loading in this study, and additional testing may be warranted. Mechanical anchors may be compromised during installation if the hole is slightly enlarged due to drill wobbling. If wobbling is a concern (i.e., drilling while suspended on rope in free space), consider using an epoxy type anchor.

Concrete anchor bolts are not the only choice for anchors. Structural anchors, such as concrete or steel that are "unquestionably" strong, are often used. Another choice of an anchor is to use a vehicle as a "deadweight" or sliding ballasted anchor. This type of anchor is typically only chosen when a suitable anchor bolt or structural anchor cannot be utilized, although a vehicular anchor has its benefits. One benefit is that a vehicular anchor does not rely on the same site conditions as a concrete anchor bolt or structural anchor. A concrete anchor bolt relies on the compressive strength of the concrete for its strength. With Reclamation's aging infrastructure, there have been instances in which the quality of the concrete was found to be questionable and not a preferable choice for an anchor bolt. The integrity of a structural anchor can similarly be called into question. For example, a structural steel anchor that appears "unquestionably" strong may have interior corrosion, or it may have been recently painted and potential corrosion areas may be hidden. In contrast to a vehicular anchor, concrete anchor bolts and structural anchors both rely on existing site conditions that are not easily observed. The only site condition a vehicular anchor relies on is the surface it sits upon, which can readily be visually inspected. Reclamation's aging infrastructure and remote locations have prompted Reclamation to consider the practicality and reliability of vehicles as anchors.

In March 2009, Reclamation performed static testing on two different vehicles used as anchors in a variety of positions and conditions. One vehicle was a 2008 Chevrolet Suburban 4x4 with a gross vehicle weight rating (GVWR) of 8,600 pounds force (lbf), and the other was a 2004 Ford Explorer 4x4 with a GVWR of 5,928 lbf. Each test was performed once. Figure 1 shows a photo of the test setup, and Figure 2 shows a schematic drawing.

Figure 1.—Photo of 2009 Reclamation static vehicle anchor testing showing Ford Explorer loaded transversely (sideways) at the trailer hitch.

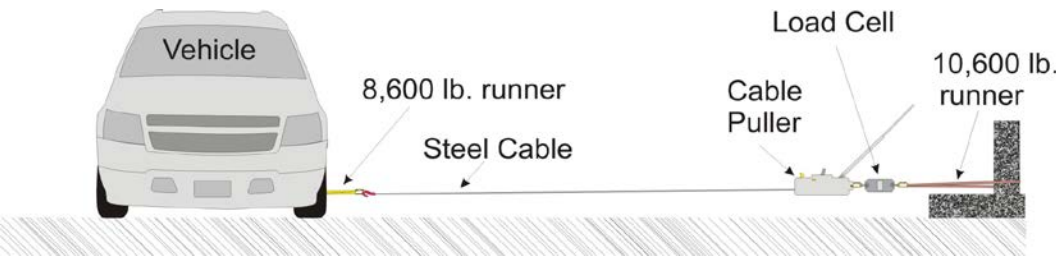

Figure 2.—Schematic diagram of typical 2009 Reclamation static vehicle anchor testing.

The primary conclusion of this testing showed that the strongest configuration was a transverse (sideways) loading connected to the middle of a vehicle's side frame. Also found to be adequately strong was a longitudinal (inline) loading at a vehicle's trailer hitch; however, very low strength was found in transverse loading at the trailer hitch (see Figure 3 below).

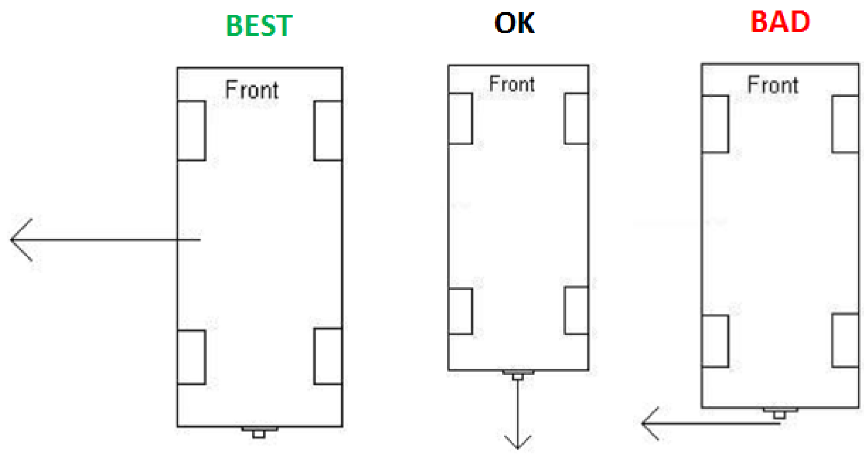

Figure 3.—Vehicle static pull testing conclusions from March 2009.

The testing also showed that only the heavier of the two vehicles (Chevrolet Suburban) exceeded a 5,000-lb static force; therefore, the testers recommended using a vehicle as an anchor only if the GVWR was in excess of 8,000 lb. See Figure 4 and Figure 5 below for the test results. In addition to the empty weight, a vehicle's GVWR also includes the fully loaded weight capacity. Although a vehicle's GVWR does not directly reflect a vehicle's unloaded weight, the GVWR can be useful since it is found posted on the vehicle itself. With the availability of information online, the empty weight of a vehicle can be easily estimated and should be considered when determining a vehicle's sliding resistance.

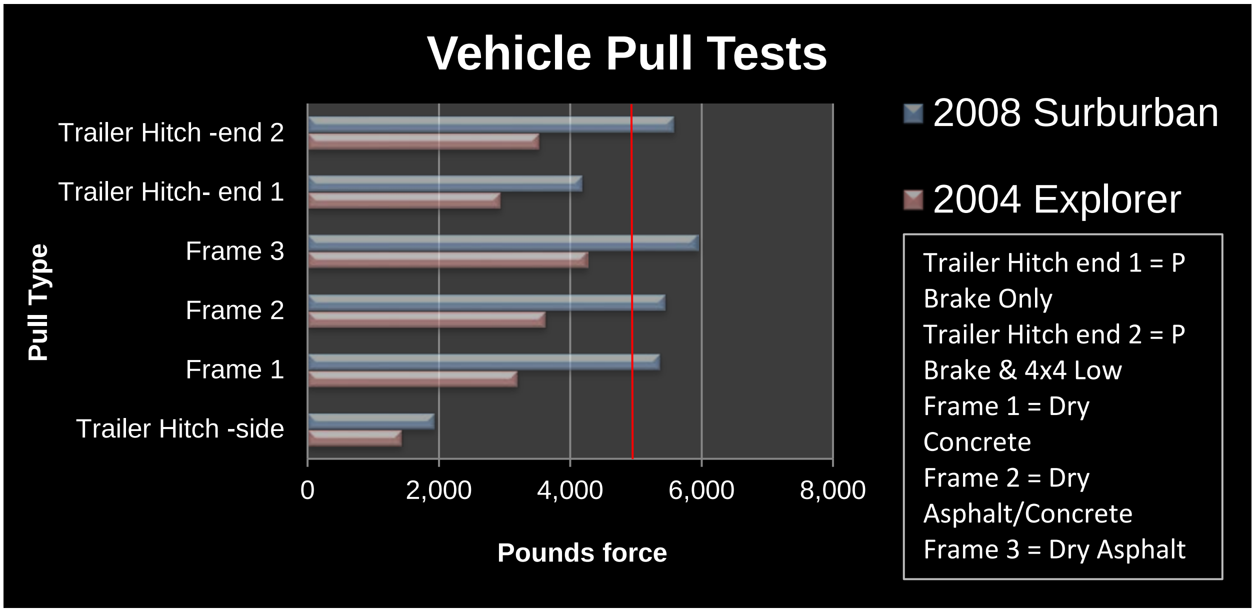

Figure 4.—Vehicle static pull testing results from March 2009 for various rigging configurations.

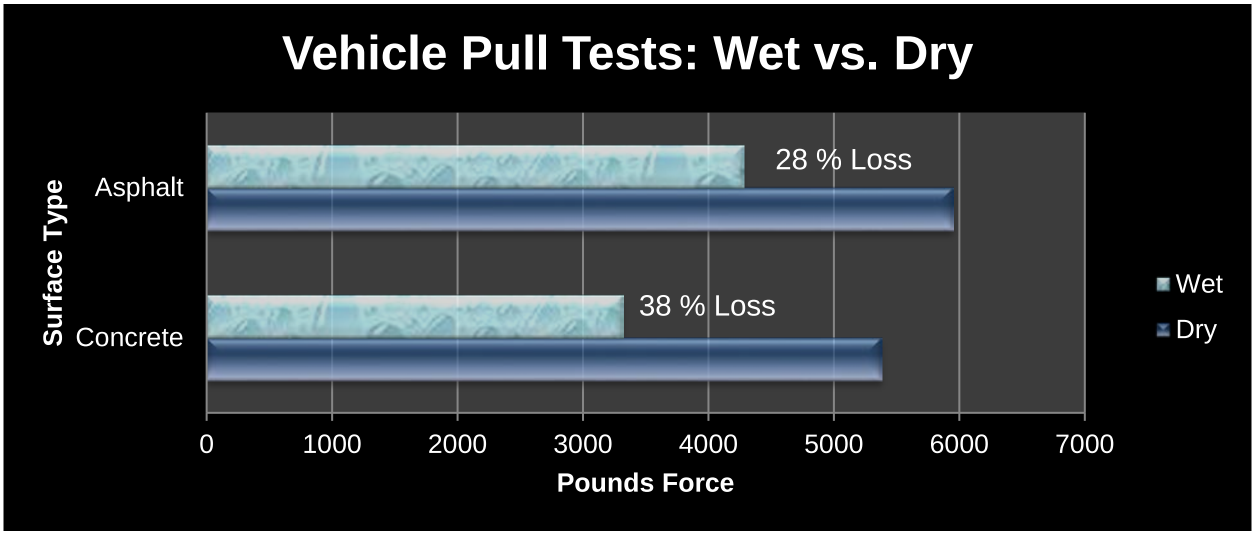

Figure 5.—Vehicle static pull testing results from March 2009 for wet versus dry conditions.

METHODOLOGY

The inspiration for the testing methodology of this project came from the Principle Investigator's work on the American National Standards Institute (ANSI) Z359.18 subcommittee for anchorage connectors. Reclamation is a voting member and is actively involved with the ANSI Z359 committee that creates standards for fall protection (including rope access). ANSI Z359 has recently (2017) published "Z359.18 – Safety Requirements for Anchorage Connectors for Active Fall Protection Systems." This standard identifies several types of anchorage connectors and specific testing methods for each type. One type of anchorage connector, Type D, is allowed to deform when it is tested. This research assumes that a sliding vehicle will be treated as a Type D anchorage connector.

For Type D anchorage connectors, the standard first requires a performance test, which is designed to produce an approximate 5,000-lbf dynamic load on a perfectly rigid anchorage connector. By definition, Type D anchorage connectors are not rigid. It is understood that some energy will be dissipated by the anchor itself; therefore, a load somewhat less than 5,000 lbf is anticipated. The load from the performance test is then multiplied by a factor to determine the static test load requirement. This factor is based on the number of users that are allowed to connect to an individual anchorage connector. In this case, a single vehicle is considered to be an individual anchorage connector.

This research project intends to approximate the ANSI Z359.18 test procedures for a Type D anchorage connector to determine the suitability of a vehicle as an anchor and to determine the number of users that can attach to a vehicle of a given weight. For simplicity, only one test surface was used, and the same test vehicle was used with different weights added to it. The results from these tests should not be assumed for other scenarios and should not be substituted for onsite testing or site-specific judgement. A qualified person (typically a professional engineer), as defined in ANSI Z359, should be consulted before using a vehicle as an anchor for fall protection.

TEST SETUP

In order to perform drop testing on a vehicular anchor in a laboratory (lab) environment, two pulleys were required to redirect the vertical force generated by the falling test mass to a horizontal force onto the vehicular anchor. One pulley was located near the top of the test tower and the other was anchored to the lab floor. The test vehicle was placed on the smooth concrete of the lab floor, oriented perpendicular to the test tower. Heavy-duty nylon rigging straps with sewn terminations were rigged to the side frame of the test vehicle with a heavy-duty shackle. Connected to the shackle was a load cell, which was connected to the test lanyard. The test lanyard ran horizontally several feet from the floor to the lower pulley, then was redirected near vertically to the upper pulley. From the upper pulley, the test lanyard was connected to another load cell with a shackle, which was connected to the test weight. A quick-release mechanism connected the test mass to the lab's bridge crane until the test mass could be released. All connectors in the test setup were heavy-duty shackles. See Figure 6 for a schematic diagram of the test setup.

Test Vehicle

Due to purchasing restrictions, a vehicle mockup (test vehicle) was fabricated using the axles and wheels from a 2004 Jeep Cherokee. Tube steel side frames were bolted and welded to the axles, and structural steel "L" shapes were welded laterally to the side frames. A plywood platform was bolted on top of the frame. This setup allowed for a quick change in various weights to be added on top of the plywood platform to simulate a test vehicle of various mass. An actual vehicle has a steering system that locks when the vehicle is parked. Since the test vehicle had no steering system, the front wheels were free to turn; therefore, lumber 2x4's were positioned between the front tires and the frame to prevent the test vehicle from turning. All four wheels were chocked with masonry bricks (Figure 7). For each test setup, all weights were secured on top of the plywood platform using ratcheting straps.

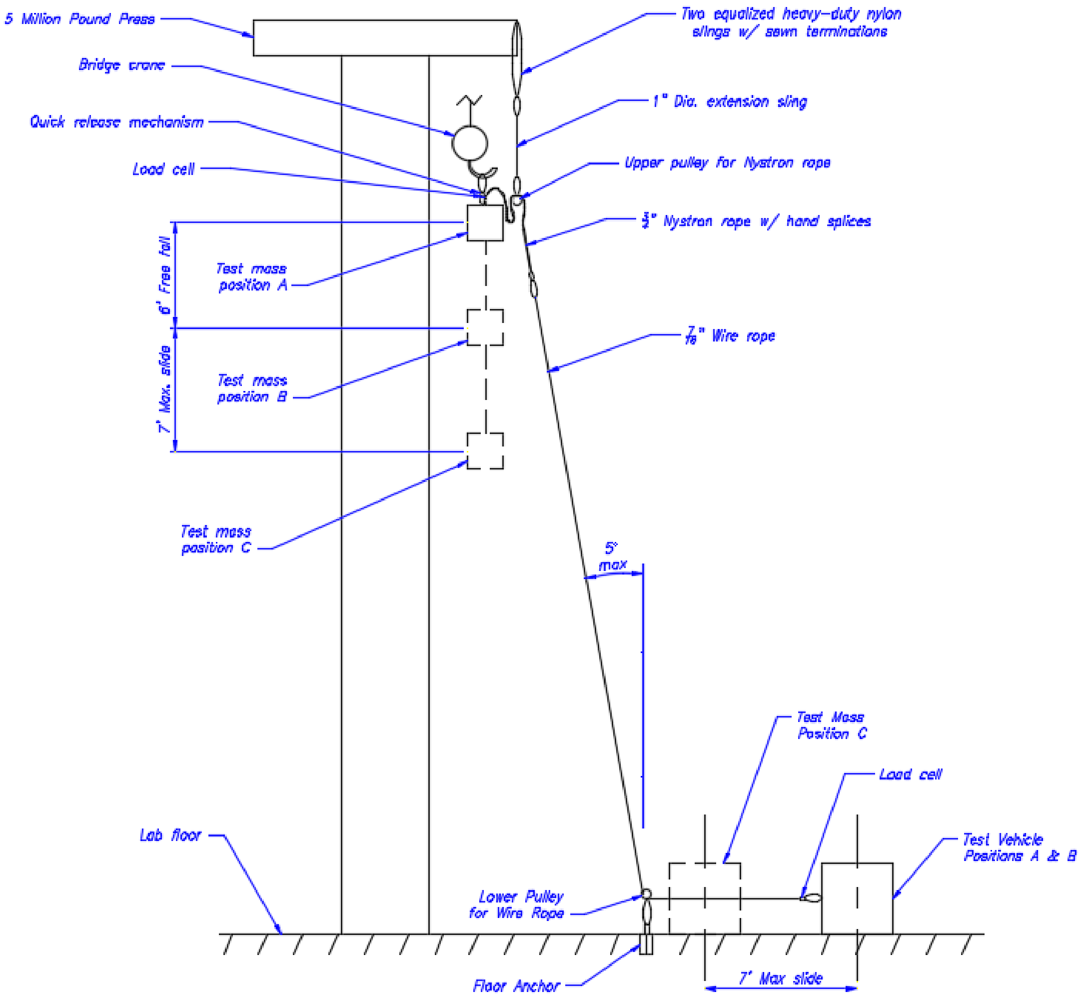

Figure 6.—Drop testing schematic.

Figure 7.—Test vehicle shown fully loaded (Test Setup #3) during load cell calibration.

Test Lanyard

A key component to ANSI Z359.18 is the test lanyard. According to the standard, the lanyard has no maximum length requirement, but it must not stretch more than 8.0 inches when statically loaded to 4,500 lbf. In order to meet this requirement, a 3/4" diameter Nystron rope, manufactured by Samson Rope Technologies, Inc. [1], was connected in series with 7/16" diameter wire rope. Although the ANSI Z359.18 requirement could have easily been achieved using wire rope alone, the stiffness would have been far too conservative to achieve meaningful results. The Nystron rope was chosen for its relative stiffness compared to other ropes, which allowed for a longer section of rope compatible with the drop height to be chosen. The Nystron rope included a hand splice at each end, and the wire rope was terminated with forged wire rope clips and thimbles.

The test lanyard was not statically tested as required by ANSI Z359.18. Instead, calculations were used to verify this requirement. For 3/4" Nystron rope, Samson indicates the average strength to be 23,000 lbf and the elastic deformation at 20% of this strength to be 4.50% stretch (Figure 8). Conveniently, 20% of 23,000 lbf is approximately equal to the ANSI Z359.18 required 4,500 lbf; therefore, 13 feet of Nystron rope at 4.50% elongation should stretch approximately 7 inches.

NYSTRON - Uncoated

PRODUCT CODE: 591

FIBER (CORE/COVER): NYLON / POLYESTER

SPECIFIC GRAVITY: 1.24

SPLICE: DOUBLE BRAID CLASS I

This double braid provides the advantages of high strength retention, good energy absorption and shock mitigation, and excellent abrasion resistance; especially in wet environments. It is fully spliceable.

ELASTIC ELONGATION:

10%	20%	30%
2.40%	4.50%	5.90%

SPECIFICATIONS:

DIAM. (inch)	CIRC. (inch)	WEIGHT PER 100 FT. (lbs)	AVG. STRENGTH (lbs)	MIN. STRENGTH (lbs)	DIAM. (mm)	CIRC. (mm)	WEIGHT PER 100 M (kg)	AVG. STRENGTH (kg)	MIN. STRENGTH (kg)
3/8	1 1/8	4.4	5,600	4,800	9	27	6.5	2,500	2,200
7/16	1 1/4	5.7	7,400	6,300	11	33	8.5	3,400	2,900
1/2	1 1/2	7.7	10,500	8,900	12	36	11.5	4,800	4,000
9/16	1 3/4	10	13,200	11,200	14	42	14.9	6,000	5,100
5/8	2	12.6	16,300	13,900	16	48	18.7	7,400	6,300
3/4	2 1/4	17.3	23,000	19,600	18	54	25.7	10,400	8,900
7/8	2 3/4	19	27,000	23,000	22	66	28.3	12,200	10,400
1	3	34	37,000	31,500	24	72	50.6	16,800	14,300
1 1/8	3 1/2	39.2	49,800	42,300	28	84	58.3	22,600	19,200
1 1/4	3 3/4	46.9	59,100	50,200	30	90	69.8	26,800	22,800
1 1/2	4 1/2	71.2	86,500	73,500	36	108	106	39,200	33,400
1 5/8	5	76.9	100,000	85,000	40	120	114	45,400	38,600
2	6	114	142,000	121,000	48	144	170	64,400	54,700
2 5/8	8	201	244,000	207,000	64	192	299	111,000	94,100
3	9	268	320,000	272,000	72	216	399	145,000	123,000

Specifications are for spliced strengths.

Figure 8.—Nystron wire rope characteristics [1].

For the remainder of the test lanyard, 7/16” extra improved plowed steel (EIPS) wire rope with 6 x 19 fiber core construction was chosen for its strength and availability. At a strength of 20,400 lbf (Webrigging Supply, n.d.), a load of 4,500 lbf would be approximately 22.1% of the strength. From Figure 9, the modulus of elasticity is 12,000,000 pounds per square inch (psi).

Elastic Stretch

Elastic stretch results from recoverable deformation of the metal itself. Here, again, a quantity cannot be precisely calculated. However, the following equation can provide a reasonable approximation for a good many situations.

$$\text{Changes in length (ft)} = \frac{\text{Change in load (lb)} \times \text{Length (ft)}}{\text{Area (inches}^2\text{)} \times \text{Modulus of Elasticity (psi)}}$$

The modulus of elasticity is given below.

Approximate Modulus of Elasticity (lbs. per square Inch)

Rope Classification	Zero through 20% Loading	21 to 65% Loading*
6 x 7 with fiber core	11,700,000	13,000,000
6 x 19 with fiber core	10,800,000	12,000,000
6 x 37 with fiber core	9,900,000	11,000,000
8 x 19 with fiber core	8,100,000	9,000,000
6 x 19 with IWRC	13,500,000	15,000,000
6 x 37 with IWRC	12,600,000	14,000,000

* Applicable to new rope, i.e., not previously loaded.

Figure 9.—Elastic stretch and modulus of elasticity for wire rope [3].

Applying the associated equation from the same figure and converting to inches yields 1.3 inches of wire rope stretch at 4,500 lbf. Combining the stretch with the Nystron rope gives 8.3 inches of stretch, which is a bit greater than the ANSI Z359.18 required maximum of 8.0 inches of stretch at 4,500 lbf. This was deemed to be adequate for the purposes of this testing.

Test Tower

The tower used was Reclamation’s custom-built five-million pound tensile test machine. It is one of the largest compression test machines in the world and is primarily used to test concrete samples. It can now be used for tension testing. For our purposes, the tower was only used as a static structure to suspend the upper pulley.

Test Mass

According to the ANSI Z359 standard, the test mass is required to be 282 lbf. This number is derived from a worker with a maximum weight of 310 lbf (including equipment). Testing has shown that a factor of 1.1 be used to compensate for the fact that the test mass is rigid, whereas a human body is not. For this testing, the test mass was constructed of two pieces of scrap steel bolted together. With the addition of shackles, the test mass weighed 303 lbf.

Quick-Release Mechanism

The quick-release mechanism was a homemade three-ring release, consisting of three different-sized steel rings that were arranged to decrease the load on a release pin (Figure 10). It is similar to a three-ring release used by skydivers to release a loaded parachute. The three-ring release system was activated by someone on the ground pulling a string connected to the release pin. The three-ring release functioned very well by cleanly and easily releasing the test mass without problems.

Figure 10.—Quick-release mechanism as a 3-ring release.

Load Cells

Two of Rock Exotica's Enforcer load cells were used to measure dynamic forces during drop testing. One load cell was connected between the test mass and the Nystron rope, and the other was connected between the vehicle anchor sling and the wire rope. The two load cells were used to measure the losses in the system. These losses were expected to be much less than a vehicular anchor in the field, where the rope would typically be redirected over an edge.

To measure static forces, a 10,000 lbf Dillon load cell was used.

Upper Pulley

The upper pulley was connected to two 3/4-inch wire ropes connected in series with a set of sewn nylon slings connecting in a load sharing configuration to the test tower.

Lower Pulley

The lower pulley was fixed to the lab floor via a shackle connected to an anchor below two embedded rails. It was necessary to use shims between the anchor and rails to prevent the lower pulley from sliding toward the test vehicle when the mass was dropped.

15-Ton Bridge Crane

The lab bridge crane runs along the ceiling above the test tower and was used to raise the test mass to the proper height to create a drop of approximately 6 feet.

STATIC TEST SETUP

For static testing, one side of a 3-ton manually operated chain hoist was connected to the Dillon load cell at the test vehicle, and the other side was connected to the floor anchor. The hoist was operated manually until the vehicle began to slide and the maximum force was recorded for each test.

RESULTS

Three test setups were each tested three times dynamically and three times statically. Although not statistically significant, three iterations of each test demonstrate consistency and is in accordance with methodologies outlined in ANSI Z359. The variable in each test setup was the amount of weight placed on top of the test vehicle. To simulate the disproportionate weight of an engine in a vehicle, a large weight (1,730 lbf) was placed near the front of the test vehicle for all of the test setups. In addition to the “engine” weight, test #1 had all four of the other deadweights evenly distributed along the plywood platform of the test weight. Test #2 had the “engine” weight in the front of the test vehicle, as it was in test #1, with two of the other deadweights evenly distributed. Test #3 had only the “engine” weight located in the front of the test vehicle as it was in the other two tests.

For the dynamic tests, the test mass was raised to the same height as the upper pulley and released with the quick-release mechanism. The free fall distance was approximately 6 feet. Figure 11 shows photos taken during pre- and post-drops.

Figure 11.—Drop testing setup pre-drop (left) and post-drop (right).

Due to the unbalanced weight on top of the test vehicle, only the rear end of the vehicle moved during any of the tests. The distance the rear tire (nearest the Press) moved was recorded as the sliding distance. The static testing setup was identical to the dynamic testing setup, except that a 3-ton chain hoist was connected to the Dillon load cell at the vehicle anchor strap, with the other end of the hoist connected to the floor anchor. Testing was terminated once the test vehicle began to move. Table 1 shows the maximum recorded dynamic forces at the test weight and the test vehicle and how far the rear tire slid during those tests. Table 1 also compares the maximum recorded static force (at the test vehicle).

Table 1.—All dynamic and static test results for three test scenarios

Test #		Test vehicle weight (lbf)	Test surface	Maximum dynamic force at test weight (lbf)	Maximum dynamic force at test vehicle (lbf)	Maximum static force at test vehicle (lbf)	Sliding distance (inches)
1	a	4,675	Lab floor	2,670	2,144	2,266	0
	b			2,930	2,198	2,234	1
	c			2,918	2,148	2,198	0
2	a	3,800	Lab floor	3,080	2,284	1,630	3
	b			2,890	2,212	1,626	2.5
	c			2,896	2,144	1,652	3
3	a	2,925	Lab floor	2,970	2,206	1,088	7
	b			2,968	2,192	1,078	7
	c			2,974	2,266	1,072	6.5

Figure 12 shows the results from Table 1 graphically. It's important to note that for each of the three iterations of a test setup, the measured values did not differ greatly from one another, which gives confidence in the repeatability of these measurements.

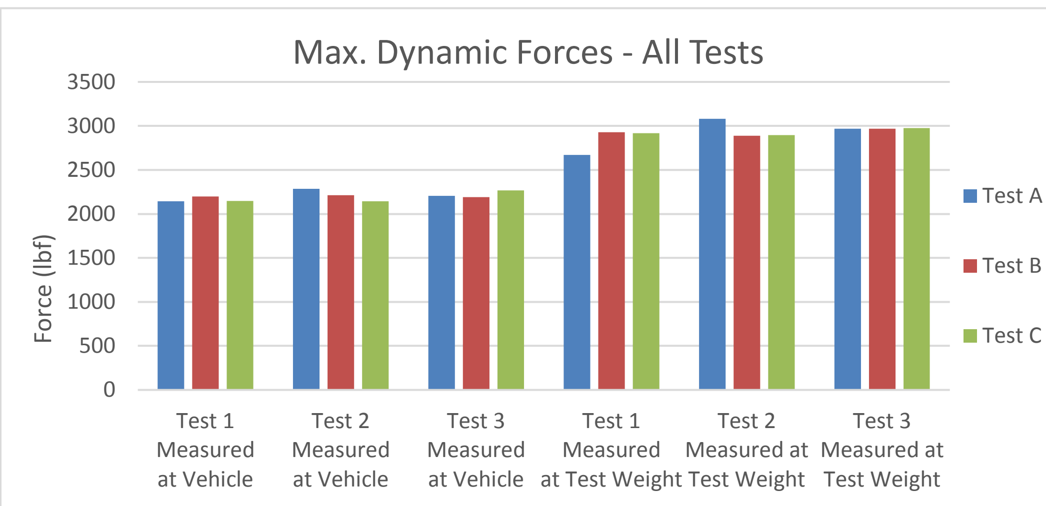

Figure 12.—Maximum forces measured for all three dynamic test setups.

Table 2 and Figure 13 show the averages of the maximum recorded forces for each test setup. As expected, the dynamic forces at the test mass were consistently higher than at the test vehicle due to the energy

Table 2.—Average dynamic and static test results for three test setups

Test #	Test vehicle weight (lbf)	Test surface	Average dynamic force at test weight (lbf)	Average dynamic force at vehicle (lbf)	Average static force (lbf)
1	4,675	Lab floor	2,839	2,163	2,233
2	3,800		2,955	2,213	1,636
3	2,925		2,971	2,221	1,079

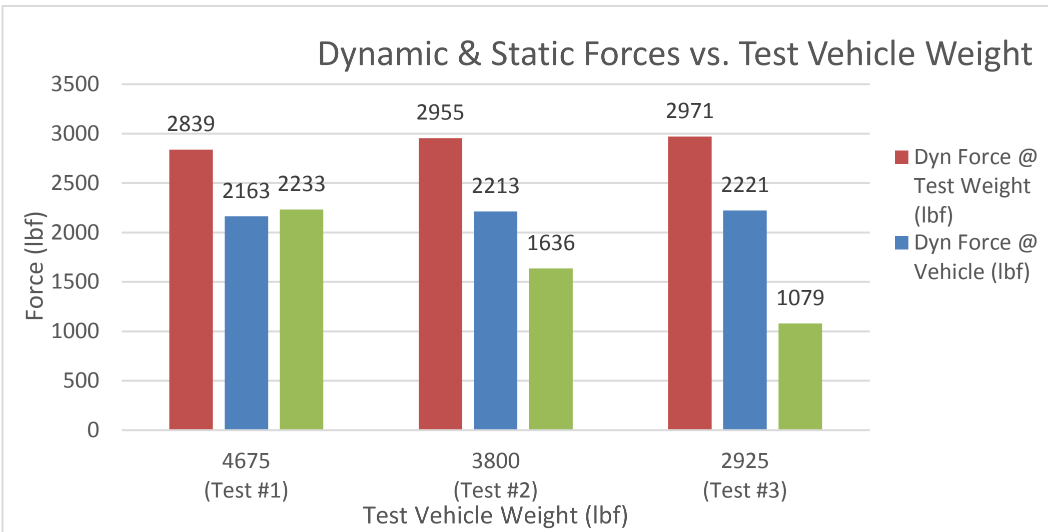

Figure 13.—Average dynamic and static forces for three test setups.

losses in the test lanyard and pulleys. Since the static forces are measured at the vehicle, it is useful to compare these values with the dynamic forces also measured at the vehicle. The dynamic force measured at the vehicle is also the required measurement for the ANSI Z359.18 performance test. It is interesting to note that the dynamic forces change very little with the change in the weight of the test vehicle; however, the static forces decrease proportionately with the decrease in the weight of the test vehicle. While the dynamic forces remain nearly the same in all three test setups, the sliding distances (shown above in Table 1) increase as the weight of the test vehicle decreases. The reason for this is not clear, but it shows that the energy is absorbed by the sliding of the test vehicle instead of resulting in a higher impact force.

Table 3 and Figure 14 show the static testing that Reclamation has previously done on actual vehicles compared with the current static testing on the test vehicle. The past testing was conducted on a 6,000-lbf Chevrolet Suburban and a 4,600-lbf Ford Explorer on smooth concrete and on asphalt. Even though past testing included many different arrangements, only the tests that anchored to the side of the vehicle with a transverse (sideways) load configuration are included in Table 3 and Figure 14.

Table 3.—Past static testing on actual vehicles versus current static testing on test vehicle

Test type	Test #	Test vehicle weight (lbf)	Test surface	Average static force (lbf)	Average sliding distance (inches)	Static friction coefficient
Past testing	Suburban	6,000	Smooth concrete	5,380	X	0.90
			Asphalt	5,950	X	0.99
	Explorer	4,600	Smooth concrete	3,200	X	0.70
			Asphalt	4,260	X	0.93
Current testing	1	4,675	Lab floor	2,233	0.33	N/A
	2	3,800		1,636	2.83	N/A
	3	2,925		1,079	6.83	N/A

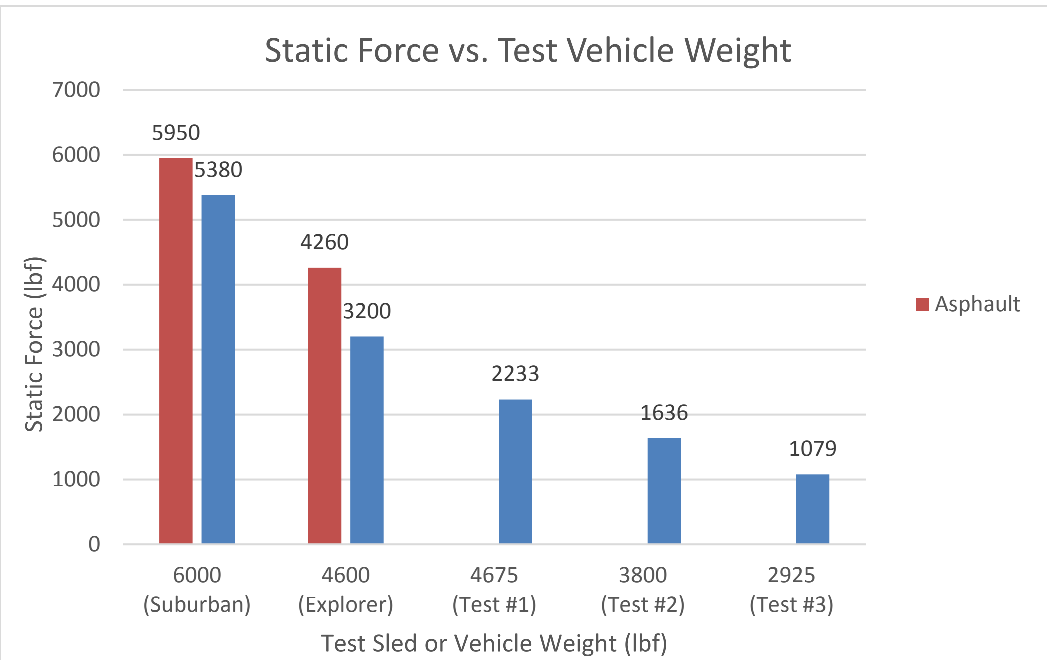

Figure 14.—Past static testing on actual vehicles versus current static testing on test vehicle.

Since the lab floor is essentially very smooth concrete, past testing of the Explorer on the smooth concrete is most similar to current test #1. Both tests were on concrete and both vehicles weighed approximately the same; however, there is still a fairly large gap in the average static force to cause sliding. Much of this is likely due to differences in the tire rubber and the surface it sits upon. Another difference is likely due to the distance of the anchor point from the center of gravity (C.G.) of the test vehicle. Since only one side of the test vehicle slid during any of the tests, the anchor point location was some unknown distance away from the C.G. The transverse (sideways) loading configuration tends to asymmetrically load a vehicle since the engine makes the front of a vehicle much heavier than the rear of the vehicle. In contrast, an anchor configuration that loads a vehicle's trailer hitch longitudinally would be a symmetrical loading configuration and would be in line with the vehicle's C.G. In fact, the vehicle testing from Reclamation in 2009 reported all wheels sliding together during the tests involving longitudinal trailer hitch loading. This loading configuration would likely yield more consistent results.

Interestingly, the dynamic forces are not dependent on the mass of the test weight but likely are due to the dynamic force acted upon it by the weight of the test mass and the distance it was dropped. Changing either the weight of the test mass or the distance it was dropped would likely change the measured dynamic forces at the test weight and at the test vehicle.

The friction coefficients were calculated by the following equation:

$$\mu = \frac{F_f}{N}$$

Where:

μ = the coefficient of friction
F_f = the force to move the vehicle
N = the weight of the vehicle

Implicit in these calculations is the assumption that all four tires are sliding simultaneously. It was not possible to calculate the coefficient of friction for the lab test setup since only one set of tires (rear) actually moved during the test and the exact weight distribution of the test vehicle was not calculated. The calculated friction coefficients ranged from 0.70 to 0.99 for the field testing that was performed previously.

RESULTS COMPARED TO STANDARDS

The testing for this research was conducted to approximate ANSI Z359.18 (2017). Other standards, such as ANSI Z359.6 (2016), were also analyzed to determine if they would be met. Reclamation's testing from 2009 was also considered.

ANSI Z359.18 (2017)

For each test configuration, the dynamic force measured at the vehicle is to be multiplied by a factor based on the number of users that can attach to the vehicle. The factors are 1.5 for one user, 2.0 for two users, 2.5 for three users, and so on. From Table 2, the dynamic forces at the vehicle can be multiplied by 1.5 and compared to the static forces measured. See Table 4 below.

Table 4.—Comparing dynamic forces to static forces according to ANSI Z359.18

Test #	Test vehicle weight (lbf)	Test surface	Average dynamic force at test vehicle (lbf)	Dynamic force x 1.5 (lbf)	Average static force (lbf)
1	4,675	Lab floor	2,163	3,245	2,233
2	3,800		2,213	3,320	1,636
3	2,925		2,221	3,332	1,079

Comparing the dynamic force values that were multiplied by 1.5 with the static force values shows that none of the static force values were high enough to meet the standard for even one user. A second caveat to the ANSI Z359.18 standard indicates the static force values must also be greater than 2,700 lbf, and none of them were. Reclamation testing from 2009 cannot be compared with this standard since no dynamic testing was done at the time. However, it is interesting to note that according to Table 3, all measured static forces for the Suburban and Explorer were well over 2,700 lbf. It is possible that those vehicles in the conditions they were tested would have met the requirements for at least one user according to ANSI Z359.18.

ANSI Z359.6 (2016)

This standard specifically addresses sliding ballasted anchors, which is what a vehicular anchor can be considered. However, ANSI Z359.6 focuses on specifications and design requirements and is therefore intended for a specifically designed system by a qualified person (typically a professional engineer) available for off-the-shelf purchase. The standard allows for either a static or dynamic analysis. For a static analysis, a factor of safety of 2.0 times the maximum arresting force (MAF) is required. A typical ANSI Z359 system has a MAF of 1,800 lbf; therefore, 3,600 lbf would be required for a designed anchorage system, which is consistent with most designed ANSI Z359 systems. Therefore, all of the configurations tested in this study would fail to meet this requirement.

SUMMARY AND CONCLUSION

Drop weight testing using a simulated vehicle as an anchor was performed in a lab environment. The test mass and test lanyard elongation were modeled after ANSI standards. Although the methods outlined by ANSI Z359.18 were followed, the dynamic test failed to produce a peak load close to the expected 5000 lb either at the drop weight or at the vehicle. This was the case whether the vehicle slid or remained stationary.

The goal of this study was to compare results between static and dynamic testing as well as between lab testing and previous Reclamation field testing of vehicle anchors. Lab testing showed that the simulated test vehicle with a weight of 4,675 lb began to slide at 2,233 lb of static load whereas a similar field test vehicle slid at 3,200 lb. Removing weight from the rear portion of the vehicle reduced the required static force for sliding. However, the maximum dynamic force remained fairly consistent while the vehicle slid for a greater distance (up to 7 inches at 2,221 lb of maximum force).

None of the lab tests met ANSI Z359.18 requirements for Type D anchors, which require that an anchor be capable of supporting the greater of 2,700 lb or 1.5 times the maximum arrest load measured at the anchor (which varied in this test from 3,245 to 3,332 lb). Likewise, the test setups did not meet ANSI Z359.6, which would require 3,600 lb static load support to meet a typical maximum fall arrest requirement of 1,800 lb. Since the 4,675-lb vehicle test weight slid an average of less than 1 inch but failed the static load requirements imposed by both ANSI standards, static testing appears to have a more stringent requirement. Static loading is also easier and more straightforward to achieve and dynamic testing and there is less potential variability introduced from a rigging system. Therefore, it makes sense to perform static testing to satisfy the 3,600-lb static strength anchor requirement of ANSI Z359.6 (2016) or to 5,000 lb, which would satisfy both ANSI standards without having to perform drop testing.

FUTURE WORK

Future testing should expand on previous work by focusing on static testing on various surfaces. In addition, a test method for static testing of a single tire should be developed and tested for correlation with a loaded vehicle. If a repeatable, correlating test method can be developed for a single mounted tire, it would allow a vehicle's spare tire to be used in the field with a load cell to estimate the force necessary to cause sliding of the loaded vehicle under specific field conditions i.e. dirt, gravel, wet surfaces, etc.

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ATTACHMENT A

Supporting Information

Datasets that Support the Final Report

- Share drive folder name and path where data are stored: Q:\mechanical\SReed_Rope Team\Anchor Testing_Vehicle Anchors

- Point of contact name, email, and phone: Dave Tordonato, dtordonato@usbr.gov, 303-445-2394

- Short description of the data: test results, background information, photos, and videos

- Keywords: rope access anchors, sliding ballast anchors

- Approximate total size of all files: 11 GB