Designation: D7401 – 08

Standard Test Methods for Laboratory Determination of Rock Anchor Capacities by Pull and Drop Tests[1]

This standard is issued under the fixed designation D7401; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the quantitative determination of the working and ultimate static or dynamic capacities of full scale rock anchors. Dynamic capacities are determined to simulate rockburst and blasting conditions (**1**).[2] The rock anchors are installed in steel pipe to simulate standard boreholes sizes. Rock anchor capacities are determined as a function of resin to steel bolt bond strength and steel bolt yield strength. These tests are not intended to determine rock anchor to borehole rock surface shear strength.

1.2 These test methods are applicable to mechanical, resin, or other similar anchor systems.

1.3 Two methods are provided to determine the capacities of rock anchors, as follows:

1.3.1 *Method A*—Using a horizontal hydraulically loaded pull test system.

1.3.2 *Method B*—Using a vertical dynamically loaded drop test system.

1.4 The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4435 Test Method for Rock Bolt Anchor Pull Test

D4436 Test Method for Rock Bolt Long-Term Load Retention Test

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions*—Refer to Terminology D653 for specific definitions.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *linescan camera*—a camera with high optical linear resolution that captures two-dimensional images by moving the object perpendicularly to the scan line.

3.2.2 *maximum load*—represents the highest load value recorded during the test.

3.2.3 *rock anchor*—usually constructed of steel, which is inserted into pre-drilled holes in rock and secured with a fixing agent for the purpose of ground control.

3.2.4 *RPM*—acronym for revolutions per minute.

3.2.5 *transverse stiffness*—the ability of the borehole or steel tube wall to deform radially.

3.2.6 *yield load*—corresponds to the onset of plastic deformation.

4. Summary of Test Methods

4.1 A rock anchor is installed in a steel pipe instead of a borehole the same manner and in the same material as its

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

intended use (2). In the Pull test, the rock anchor is hydraulically pulled horizontally and the displacement of the bolt head is measured concurrently. The bolt is pulled until the anchor system fails (or to the ultimate stroke of the ram). The ultimate and working capacity of the rock anchor is calculated from the plot of load versus displacement. In the Drop test, a known mass is released vertically impacting on a plate at a preset distance that is in turn affixed to the end of a rock anchor. The maximum energy is expressed in kJ.

5. Significance and Use

5.1 For a support system to be fully effective, the support system must be able to contain the movement of rock material due to excavation stress release, slabbing, etc. Data from the load tests are used by engineers to design the appropriate support system to improve safety and stability of underground support systems. Test Methods D4435 and D4436 are used for in-situ load tests.

5.2 The local characteristics of the rock, such as roughness and induced fractures, are significant factors in the anchor strength. The material used to simulate the borehole surface should be sufficiently roughened so that failure occurs in the rock anchor and not at the simulated anchor-rock surface. In the case of steel pipe, internal threading using different spacing and depth is accomplished using a machinist's lathe to simulate roughness.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of these factors.

6. Apparatus

6.1 *Components Common to Both Test Methods:*

6.1.1 The manufacturer provides the rock anchors, plates, nuts, domes, washers, bottom plate, resins, and steel tubes for the tests. The manufacturer specifies the borehole size, type of resin, penetration rate and rotation rate for the installation of the rock anchor and any other installation information.

6.1.2 Upon receipt, the rock anchor measurements include length, rod diameter, length and diameter of the threaded part, length and diameter of the mixing element and any specific characteristics.

6.1.3 Boreholes are simulated by 12 mm-thick cold rolled steel tubes of the required internal diameter. The steel tube preparation includes a slight roughening of the inside surface over approximately the last meter. This roughened section is referred to as the top of the tube. Two sets of 25.4 mm holes are drilled near the top of the tube. The top set supports the tube in the drop test apparatus and the lower holes allow access to the end of the rock anchor after installation. For each rock anchor, two holes are drilled through the top end of the rock anchor to allow the clevis to be attached during testing.

6.2 *Method A—Pull Test System (Static):*

6.2.1 A double acting hollow hydraulic ram, with a minimum load capacity of 325 kN and displacement of 150 mm is recommended for this test. Displacement positioning of the ram is accomplished using a hand operated pump. A hand pump is used during the controlled loading. Once the rock anchor or the resin starts to fail, an electric pump (Px) can be used until the specimen fails or the ram reaches its stroke capacity. Fig. 1 displays a typical pull test set-up.

6.2.2 The ram hydraulic pressure is monitored using an electronic pressure transducer. Two 25.4 mm stroke potentiometers with a resolution of 0.6 mm are recommended for displacement measurements. The potentiometers measure the plate and the end displacements during the test. All instruments are connected to a data acquisition system.

6.3 *Method B—Drop Test System (Dynamic):*

6.3.1 The drop or dynamic test system (Fig. 2) shall accommodate a height of drop of the mass of at least 2.0 m below the coupler pin. The mass capacity of 1 ton, (1T) shall not be less than 325 kN. As the energy input is controlled by the drop height and the mass, the maximum energy available and the maximum impact velocity that each drop can reach are 62 kJoules and 6.5 m/s, respectively.

6.3.2 Instrumentation used to measure the loads and the displacements are measured at the plate and at the end of the rock anchor. Displacements in some systems are measured using linescan cameras. The cameras are sampled at 10 000 lines per second to match the sampling of the analog signals. The lines are amalgamated to form an image of distance versus time. The location of black and white targets attached to the plate nut or to the bolt end, is detected within the image. This system measures loads using arrays of four piezoelectric force sensors, sandwiched between two platen rings.

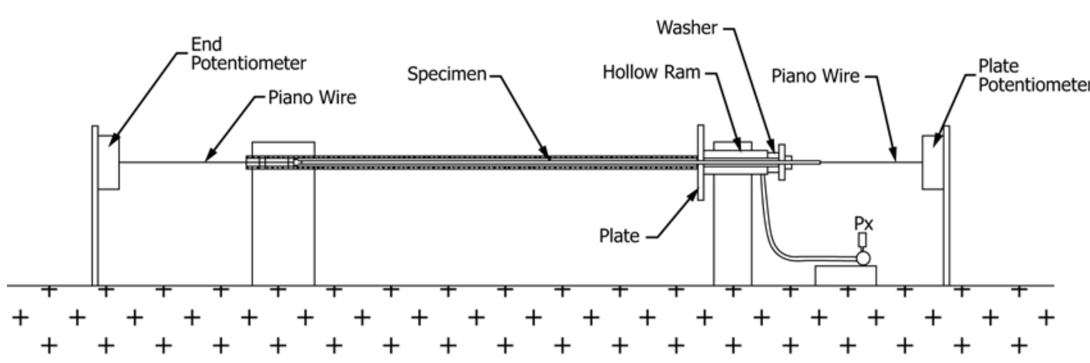

FIG. 1 Schematic of Pull Test System

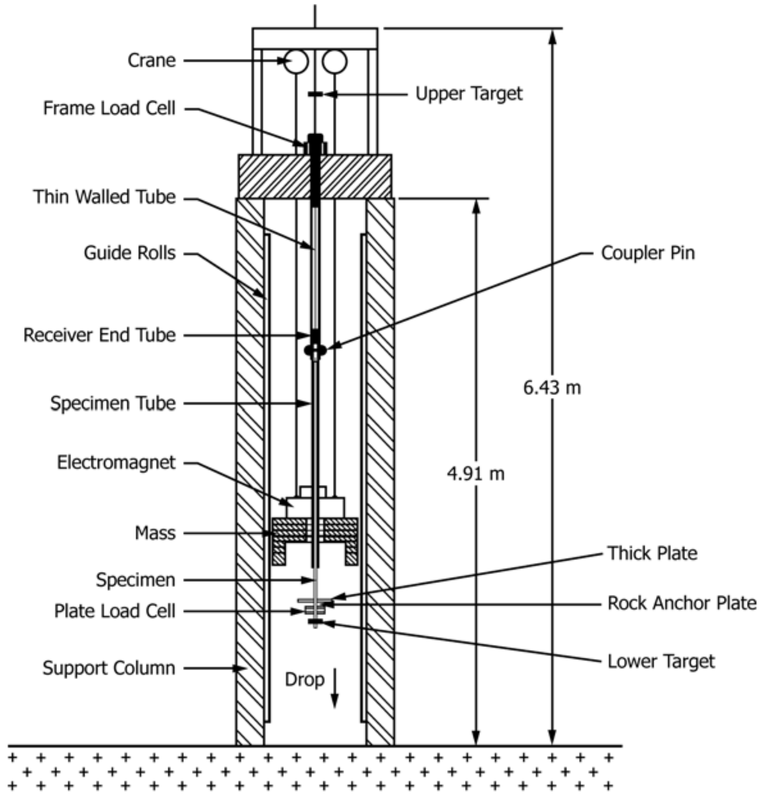

FIG. 2 Schematic of Drop Test System

6.3.3 All instruments are connected to a data acquisition system. The impact duration is typically 60 ms, but data are recorded for about 1.5 s before and up to 5 s after the impact to ensure that all instruments have stabilized.

7. Procedure

7.1 *Encapsulated Resin Anchor Bolt Specimen Installation:*

7.1.1 Insert into the tube (see Fig. 3), a plug, which extends from the top of the specimen tube to below the second set of 25.4 mm holes. This prevents the end of the rock anchor and the resin from being installed past this point.

7.1.2 Insert additional plugs into the bottom set of holes to prevent resin from escaping during installation.

7.1.3 Place the specimen tube in a jig to align it with the drill.

7.1.4 Prior to installation, slide the rock anchor specimen completely into the tube.

7.1.5 Mark the collar position and orientation of the mixing element on the rock anchor specimen. These lines are used during installation to ensure that the rock anchor is fully inserted and to identify the paddle orientation.

7.1.6 Thread the two nuts completely onto the rock anchor and tighten them in order to seat the drill chuck.

7.1.7 Remove the rock anchor and slide the resin cartridges are into the end of the tube.

7.1.8 Insert the rock anchor into the chuck, which is attached to a drill mounted on a sliding rail with an independent advance drive system.

7.1.9 Spin the rock anchor into the tube at a steady advancement and constant RPM rate.

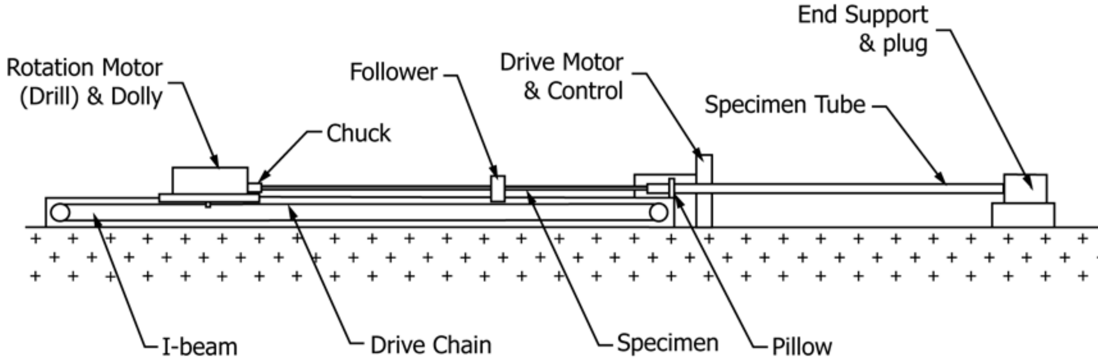

FIG. 3 Schematic of Installation System

7.1.10 Once the rock anchor reaches the plug, stop the advance and rotate the rock anchor for an additional 5 seconds.

7.1.11 Remove the drill and rotate the lines, indicating the mixing element orientation, to the horizontal.

7.1.12 Remove the tube from the jig, and remove all the plugs.

7.1.13 Remove any resin beyond the end through the holes in the tube.

7.1.14 Clean the mixing element and the end of the rock anchor, including its two small holes.

7.1.15 An electric motor (1 hp), capable of generating 150 to 400 RPM, is used to simulate the mechanized (that is, bolter) installation. The installation set-ups are tightly controlled in order to improve the mixing and to minimize the differences in mixing quality between specimens. The set-ups can be readily adjusted to provide the penetration rate and rotational speed required.

7.2 *Method A—Pull Test:*

7.2.1 Attach a 1 m long high yield strength wire (piano wire) to the end of the rock anchor, and feed the wire out the top of the tube.

7.2.2 Reinstall the tube in the installation jig and connect the piano wire to a potentiometer.

7.2.3 Install the 300 mm diameter–12 mm thick steel plate, 150 mm stroke 325 kN hollow ram and the heavy washer over the end of the rock anchor up against the tube. Thread on the nut on and tighten the entire assembly.

7.2.4 Attach the second potentiometer to the nut.

7.2.5 Use the potentiometers to measure the plate and the end displacements during the test.

7.2.6 Use both a hand pump and an electric pump to power the hollow ram. Use the hand pump during the test prior to rock anchor failure.

7.2.7 Once the rock anchor or the resin starts to fail, use the electric pump until the specimen fails or the ram reaches its stroke capacity.

7.3 *Method B—Drop Test:*

7.3.1 Set-up the predetermined mass to be dropped.

7.3.2 Install the clevis on the end of a thin-walled tube that runs up through the center of the support assembly for the specimen tube. The clevis connects the thin-walled tube to the end of the rock anchor.

7.3.3 Measure the end displacement with a linescan camera, which monitors a target on the thin-walled tube.

7.3.4 Insert the rock anchor through the center of the magnet and the mass.

7.3.5 Insert the top of the specimen tube into the receiver end of the drop test support assembly. A 25.4 mm bolt suspends the tube in place. The 25.4 mm bolt has a small hole through its middle to allow for the passage of the clevis to the end of the rock anchor.

7.3.6 Lower the clevis onto the end of the rock anchor.

7.3.7 Use two machine screws to attach the clevis to the cone.

7.3.8 Lower the magnet on to the mass.

7.3.9 Lift the mass with the overhead crane hoists.

7.3.10 Install the 12 mm-thick impact plate, the rock anchor plate, the dome washer and the threaded nut on the threaded end of the cone bolt.

7.3.11 Install the target under the threaded nut, for the lower linescan camera.

7.3.12 Calibrate the lights and the two linescan cameras (lower and upper).

7.3.13 Lower the mass onto the impact plate.

7.3.14 Move the crane hoists from the mass to the magnet.

7.3.15 Start the data acquisition system.

7.3.16 Lift the mass magnetized to the electromagnet to the desired height. The electromagnet is lifted with the pair of synchronized cranes mounted on the top of the machine.

7.3.17 Cut the power to the magnet, to free fall the mass onto the specimen.

7.3.18 Acquire data from the plate and end displacement monitors.

7.3.19 Acquire data from the load cells attached to the frame above the specimen and below the plate. Use a suitable frame load cell such as an array of four piezoelectric force sensors sandwiched between two platen rings. Locate sensors on top of the frame crossbeams. Locate another set of piezoelectric sensors on the threaded part of the bolt just below the plate.

7.3.20 Use linescan cameras to acquire displacements at 10 000 lines per second to match the sampling of the analog signals. The location of a black and white target, attached to the plate nut or to the end, is detected within the image. Linescan camera lines are amalgamated to form an image of distance versus time.

7.3.21 Drops could be repeated until the rock anchor fails or until the appropriate cumulative amount of energy desired is reached.

7.4 *Post Test Inspection:*

7.4.1 Mechanically cut specimens open lengthwise after testing is completed.

7.4.2 Compare the actual end displacement to the test results.

7.4.3 Inspect visually and record the quality of the resin mixing visually based on color, relative hardness, or both.

TABLE 1 Geometric Description of the Rock Anchors (typical)

Rock Anchor (for conebolt)	Max Cone Diameter (mm)	Min Cone Diameter (mm)	Cone Angle (°)	Cone Length (mm)	Rod Diameter (mm)	Bolt Length (mm)	Lip[A] (mm)
MCB33	22.87	17.48	5.5	55.66	17.16 (Area: 231.27 mm^2)	2235.63	–0.32
MCB38	26.47	18.97	7.8	54.60	17.27 (Area: 234.25 mm^2)	2246.26	1.70

[A] The Lip is defined as the difference between the rod and the minimum cone diameters.

TABLE 2 MCB38 and MCB33 Specimen Tube Specifications (typical)

Rock Anchor	Tube Length (mm)	Outside Tube Diameter (mm)	Inside Tube Diameter (mm)	Length of Reamed Portion (mm)
MCB33	2134.78	60.41	34.67	1012.74
MCB38	2134.00	63.53	37.84	1017.00

8. Calculations

8.1 The Transverse Stiffness, K_T, represents the ability of the borehole or steel tube wall to deform radially and is defined as follows (**3**). Calculate the Transverse Stiffness as follows:

$$K_T = \frac{2E}{(1+\nu)} \cdot \left\{ \frac{d_o^2 - d_i^2}{d_i\left[(1-2\nu)\, d_i^2 + d_o^2\right]} \right\} \quad (1)$$

where:

K_T = Transverse stiffness, MPa/mm,
E = Young's modulus, GPa,
ν = Poisson's ratio,
d_o = external pipe diameter, mm, and
d_i = internal pipe diameter, mm.

8.2 Calculate the Impact Velocity, *Vi* as follows:

$$Vi = (2 \cdot 9.81 \cdot h)^{1/2} \quad (2)$$

where:

Vi = impact velocity, m/s, and
h = height, m.

8.3 Calculate the Impact Energy, *Ep* as follows:

$$Ep = \frac{(9.81 \cdot w \cdot h)}{1000} \quad (3)$$

where:

Ep = impact energy, kJ,
w = mass, kg, and
h = height, m.

8.4 Other parameters measured include displacements, energy absorbed and strains calculated over the entire and effective un-embedded lengths of the rock anchor.

8.5 The displacement of the end bolts are measured to differentiate between the plate displacements caused by the bolt sliding versus steel elongation (frictional resistance).

NOTE 2—Detailed analysis identifies several parameters including the Yield Load and Maximum Load (see Table 4).

8.6 Drop test results are analyzed and reported as shown in Table 5 based on the plate and end displacements, which are measured digitally using the linescan images, and the load cell data.

8.7 The loads, determined from the load/time plots as shown in Fig. 5, show an initial peak (that is, Peak Load) that generally exceeds the static capacity of the steel, followed by a trough and reloading to a peak or plateau that is referred to as the "average" load or ultimate holding capacity of the bolt. The graph includes the frame and the plate loads together.

8.8 The plate and end measurements are recorded after the impact, when the specimen has stabilized.

TABLE 3 Installation Parameters for Testing Rock Anchors (typical)

Bolt	Tests	Average Range (RPM)	Average Insertion Time (s)	Resin Used
MCB33	7 day curing	175–200	23	Fastloc 30 mm 30 in 2–4 min curing (2 cartridge)
	1–3 day curing	310–360	23	Coneloc 30 mm 20 in 2–4 min curing (3 cartridge)
MCB38	Greased non-greased	165–190	24	Conflec 1⅜ in. × 30 in 1 min curing (2 cartridge)
MCB38	At 40°C	330–380	23	Coneloc 1⅜ in. × 30 in 2–4 min curing (2 cartridge)

8.9 Manual measurements of plate and end displacement are recorded after each impact and compared to the digital record.

9. Report

9.1 Report the following information:

9.1.1 The manufacture's specifications for rock anchors.

Example:
MCB38 and MCB33 bolts
C1055 Modified steel
Minimum yield strength: 448.2 MPa (Yield Load: 104.4 kN)
Ultimate tensile strength: 689.5 MPa (Ultimate Load: 160.6 kN)
Minimum elongation: 10 %
Thread type: ¾ in. – 10LH rolled thread

9.1.2 The geometric characteristics of the rock anchor specimens as shown in Table 1.

9.1.3 The 12 mm-thick steel tubes simulating the borehole as shown in Table 2.

9.1.4 The installation parameters, including resin used, as shown in Table 3.

9.2 *Method A—Pull Test Report :*

9.2.1 Include plotted test data shown in Fig. 4.

9.3 *Method B—Drop Test Report :*

9.3.1 Include plotted test data shown in Fig. 5.

10. Precision and Bias

10.1 *Precision*—Test data on precision is not presented due to the nature of rock anchors and fixing materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

10.2 The Subcommittee D18.12 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

10.3 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

11. Keywords

11.1 impact energy; impact velocity

TABLE 4 Basic Parameters Measured During the Pull Tests (typical)

Bolt Type	Yield Load (kN)	Maximum Load (kN)	Plate Displacement (mm)	Energy Absorbed (kJ)	Strain L1 (%)	Strain L2 (%)
MCB38 – G	125.0	168.4	144.0	18.9	6.41	19.92
MCB33 – G	122.8	167.3	148.0	18.9	6.62	20.79

TABLE 5 Parameters Measured During Drop Test (typical)

Drop	Drop Height (m)	Input Energy (kJ)	Impact Velocity (m/s)	Incr. Plate Displ. (m)	Cum. Plate Displ. (m)	Frame Pot Displ. (m)	Cone Displ. (m)	Cum. Cone Displ. (m)	Steel Stretch Plastic (m)	Steel Elong. % Strain	Cum. Strain (%)	Cone Displ. % of Total	Peak Load (kg)	Avg. Load (kg)	Plate Peak Load (kg)	Plate Avg. Load (kg)
1	1.500	16.01	5.425	0.104	0.104	1.605	0.074	0.074	0.030	1.34	1.34	71.2	23840	15710	31720	15200
2	1.500	16.01	5.425	0.090	0.194	1.567	0.001	0.075	0.090	4.00	5.34	0.6	23270	18850	25510	23370
3	1.500	16.01	5.425	0.124	0.318	1.591	0.121	0.196	0.003	0.13	5.47	97.6	27870	16050	21550	16420
4	1.500	16.01	5.425	0.054	0.372	1.572	0.000	0.196	0.054	2.40	7.87	0.6	23100	20130	24910	21860

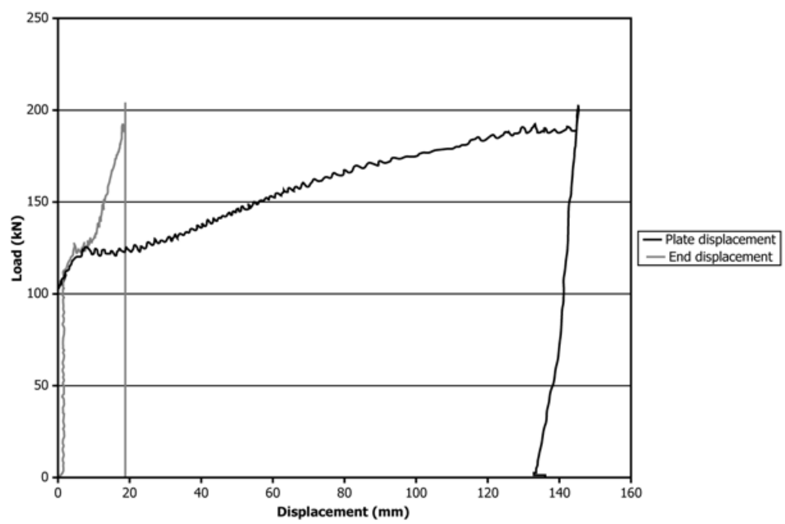

FIG. 4 Load–Displacement Graph from Pull Test for Rock Anchor (typical)

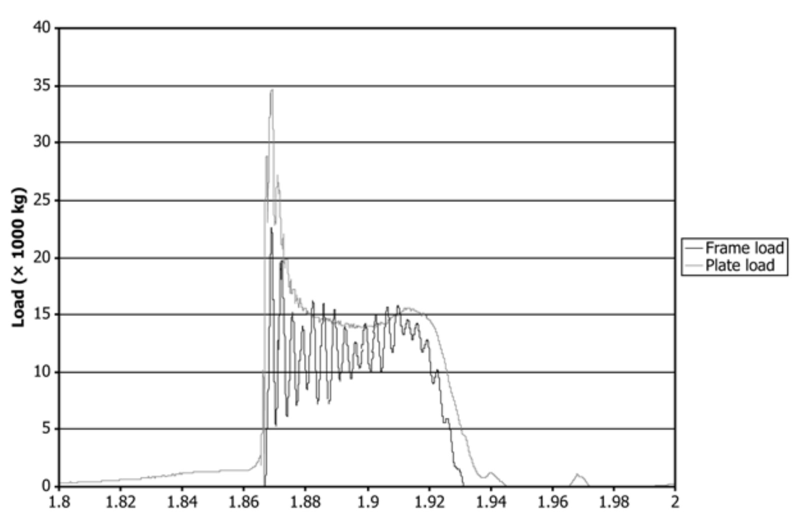

FIG. 5 Load–Time Graph for Drop Test Showing the Values Recorded by the Frame and Plate (typical)

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