VIBRALOCK® Report from Laboratory Test

WorkSpace name: VIBRALOCK® - Commercialization Project

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1 Executive summary

1.1 Introduction

Bondura Technology AS has developed a nut-locking system named VIBRALOCK® for use in all types of bolted connections. The objective of the test was to prove that the VIBRALOCK® system can prevent loosening of the nut and retain a much higher preload compared to regular bolted systems, while still being easy to disassemble with the same torque and tension tool used for installation.

The bolt system was tested at alternating transverse loading to determine the resistance against loosening and loss of preload. Testing was performed comparing VIBRALOCK® with HV structural bolting assemblies using defined preloads. Strain gauges was mounted on the shank of the bolts to measure the tension force during testing.

The test procedure was developed by DNV GL AS Oil & Gas, Laboratory & Testing – Oslo in accordance with ISO 16130:2015 as a Junker vibration test. Location of test was at the University of Stavanger, Norway.

This is the basis for evaluation of the VIBRALOCK® system.

European Patent application no. 16839680.2
United States application no. 17/287,602, United States publication no. US 2021/0396268 A1

1.2 Test scope

The test jig was designed to test bolts of grade 10.9 in sizes M30x3.5 and M42x4.5 with a clamping length of 4 times the diameter. All parts of the bolt assemblies are hot dip galvanized.

Preload of the bolts is achieved by both tensioning of the shank and turning of the nut.

Strain gauges monitored the preload of the bolts, and displacement transducers monitored how much transverse movement was introduced to the surface plates where the bolted assemblies were clamped.

The test machine was running by amplitude control to a pre-set value for each test, and continuously logging the transverse force needed to achieve the amplitude.

ISO 16130:2015 define the following ratings of self-locking behaviour:

Rating	Explanation	Relative clamp force loss
1	Good self-locking behaviour	0% - 15%
2	Acceptable loss of clamp force	15% - 60%
3	Poor self-locking behaviour	60% - 100%

<u>Test Equipment:</u>

- MTS Series 809 Axial/Torsional Test Systems – Model 319.25
- MTS FlexTest 40 Controller & Series 793 Software
- Transverse Load Jig
- BLACKIRON 1000 kN Hydraulic Load Cell
- BLACKIRON Bridge for EN14399-4 & Vibralock
- BLACKIRON Conversion Kit M30 & M42
- BLACKIRON Electric Pump 1500 bar & 5 mtr hose
- TORQLITE IU-3XL with 50 mm head
- TORQLITE IU-7XL with 70 mm head
- TORQLITE Electric Pump 700 bar & 4,5 mtr twin hose

<u>Measurement Equipment:</u>

- HBM QuantumX MX440B & MX1615B with Catman AP software
- HBM WA-T Inductive Displacement Transducer
- Strain Gauge Full Bridge configuration on each bolt

2 Test Setup

2.1 Setup

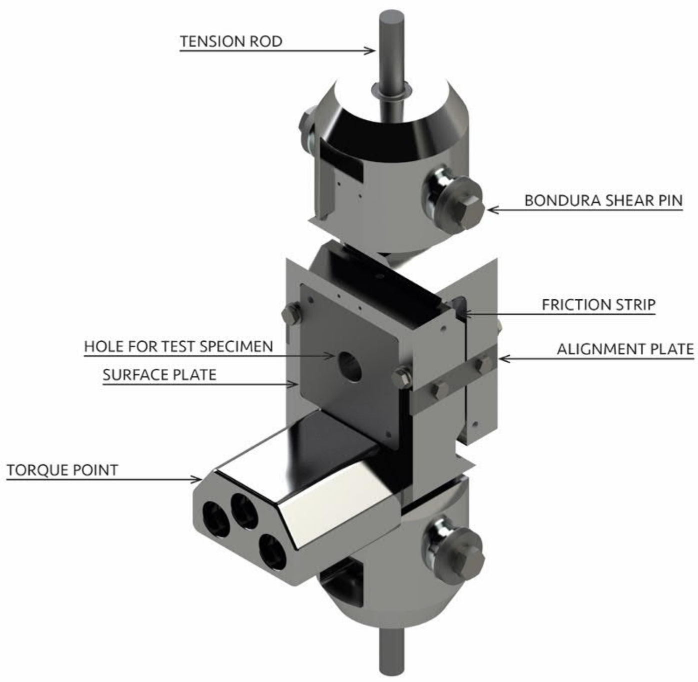
The machine used for testing is located at the University of Stavanger and is used as a fatigue testing machine that can achieve the load, amplitude and frequency needed for the test.

The load jig was designed for this scenario specifically with two main structure plates where one is moving by connection it to the hydraulic cylinder while the other is stationary.

The jig is connected to the machine by a tension rod and pivot pin connection on the top and bottom. A POM gliding plate is located between the two structure plates to reduce friction and provide a smooth and even movement of the jig.

Replaceable surface plates were used under the bolt head and the nut to ensure the same surface conditions for each test. Alignment plates were used for the installation of bolts to centre the test samples.

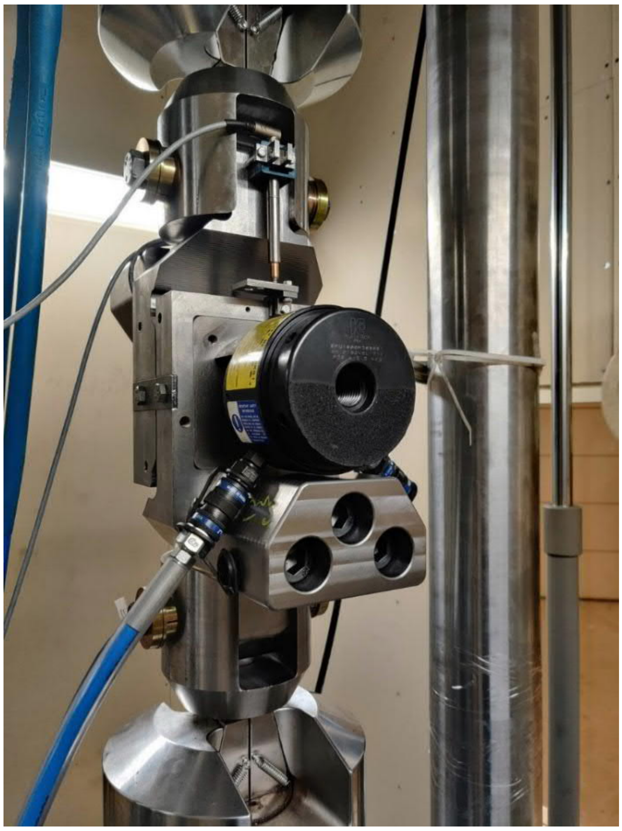
Molykote® G-Rapid Plus were used as thread and assembly paste to maintain a consistent friction coefficient between threads and surfaces for the duration of the test.



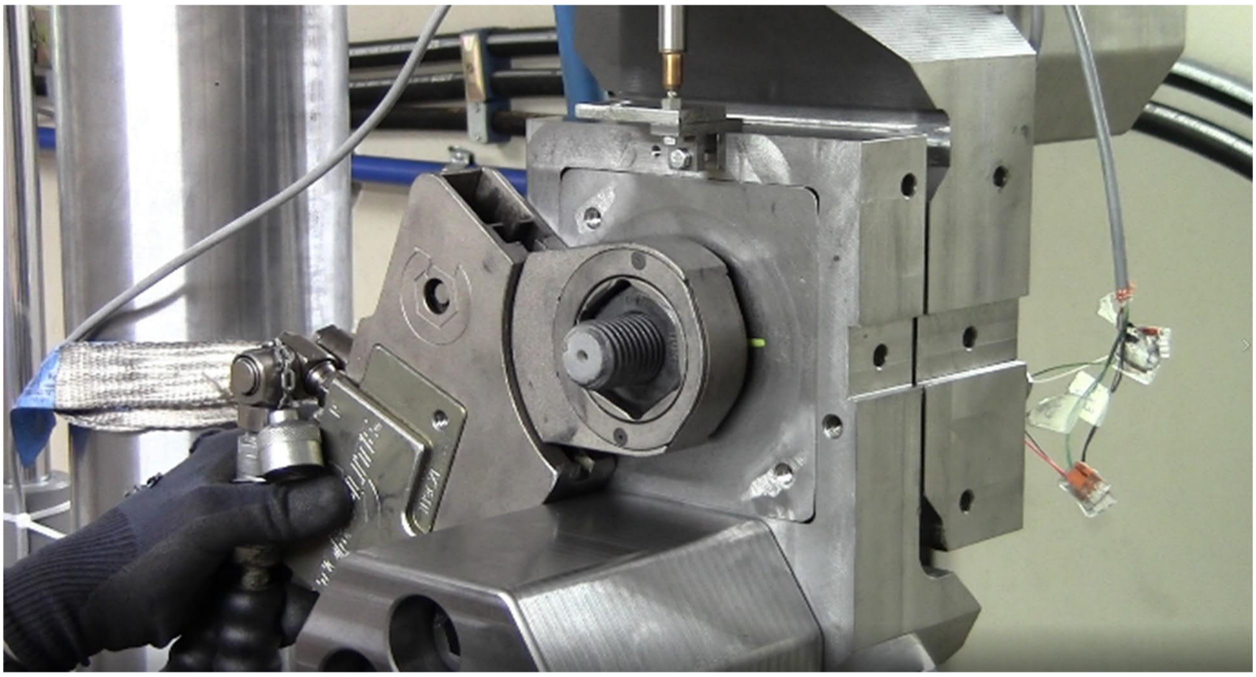
Transverse Test Jig

Test Samples

Tension Tool



Torque Tool



2.2 Instrumentation

Description	Instrument type	Comment
Relative movement	Two displacement transducers on structural plate elements	Zero point set every test
Clamp force	Two strain gauges on bolt shank	Full bridge configuration
Actuator force	Load cell	System control
Actuator displacement	Displacement transducer	System control

The actuator force and displacement were logged by the MTS test machine control unit and computer. Data from the strain gauges and displacement transducers were logged by a HBM QuantumX data acquisition device via Catman AP. The test frequency of amplitude was 1 Hz with data logging of 100 Hz.

2.3 Test program

Tension and torque tools were used to achieve the preload specified in order to test both methods.

A few test runs were necessary in the beginning to determine the correct amplitude to use for testing where the reference bolts lose close to 90% preload before 400 cycles. Subsequently, reference tests of HV assemblies was repeated 3 times with the determined amplitude.

The VIBRALOCK® assemblies were tested for verification of the system with a minimum of 3000 cycles for each test samples.

The following parameters were logged; amplitude, preload at start, preload at end, number of cycles and the loss of preload over the duration of the test (calculated).

Size	Clamped thickness [mm]	Preload [kN]	Calculated torque [Nm]	Hole diameter [mm]	Expected relative movement [mm]
M30x3.5	120	353	1800	33	1,02
M42x4.5	168	706	5000	45	1,46

Test Samples:

- Bolt/nut Assembly EN 14399-4 – HV – M30 x 185 x 74 – 10.9/10 – tZn – K1
- Bolt/nut Assembly EN 14399-4 – HV – M42 x 260 x 135 – 10.9/10 – tZn – K1
- VIBRALOCK® M30 x 175 x 64 – 10.9/10 – tZn – K1
- VIBRALOCK® M30 x 195 x 84 – 10.9/10 – tZn
- VIBRALOCK® M42 x 240 x 99 – 10.9/10 – tZn – K1
- VIBRALOCK® M42 x 275 x 134 – 10.9/10 – tZn

3 Test Results

3.1 Results M30

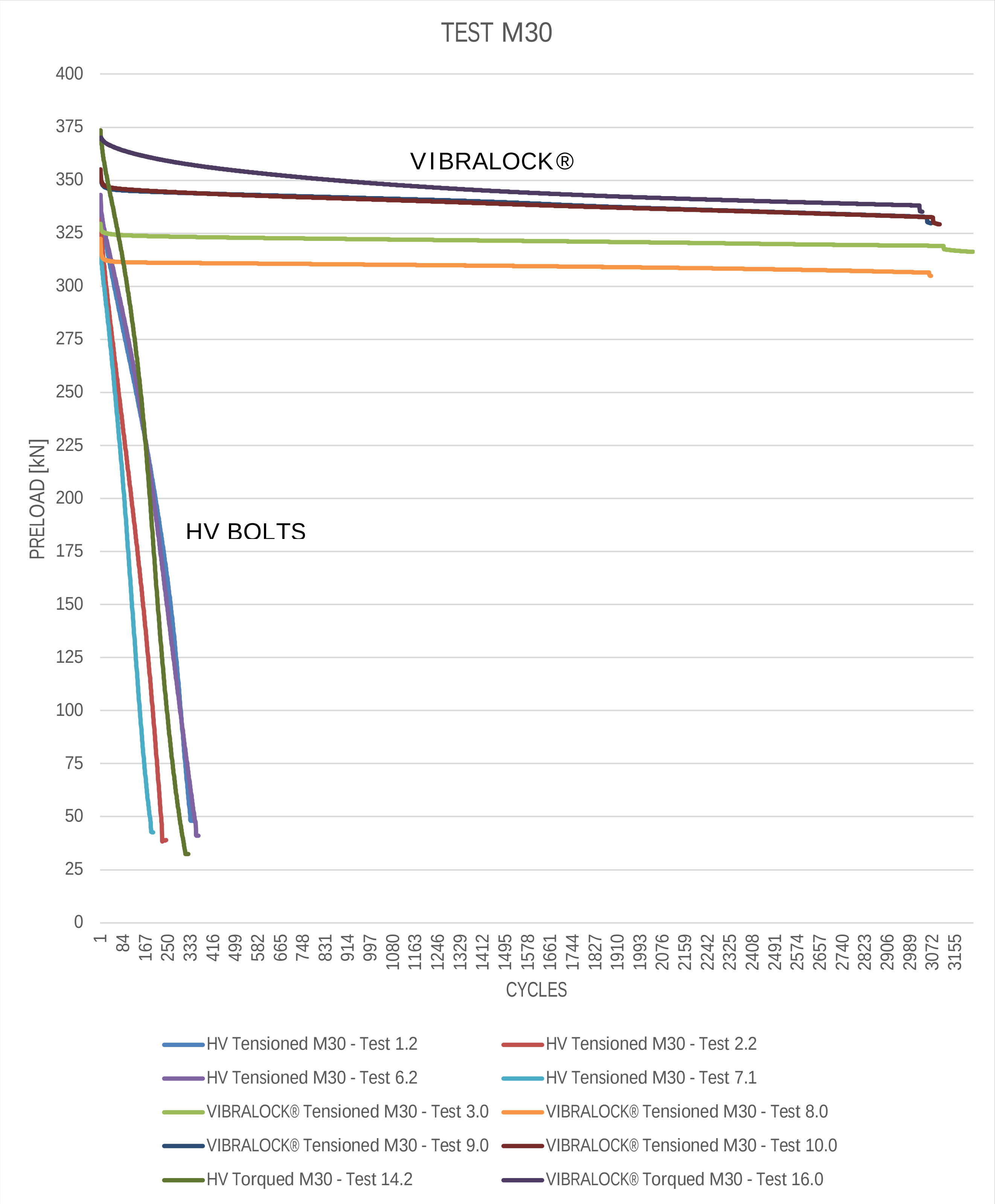
HV Tensioned M30							
Test #	SG #	Date	Amplitude [mm]	Preload Start [kN]	Preload End [kN]	Preload Loss %	Cycles run
1.2	2	11.11.21	±0,72	334,1	47,9	85,7 %	333
2.2	3	11.11.21	±0,82	329,3	38,9	88,2 %	228
6.2	18	15.11.21	±0,98	343,3	41,0	88,1 %	353
7.1	20	15.11.21	±1,06	320,1	42,8	86,6 %	187

VIBRALOCK® Tensioned M30							
Test #	SG #	Date	Amplitude [mm]	Preload Start [kN]	Preload End [kN]	Preload Loss %	Cycles run
3.0	1	12.11.21	±0,76	329,6	318,4	3,4 %	3114
8.0	5	15.11.21	±0,98	322,8	305,3	5,4 %	3061
9.0	24	15.11.21	±0,97	353,7	331,1	6,4 %	3053
10.0	22	15.11.21	±0,98	355,2	330,0	7,1 %	3075

HV Torqued M30							
Test #	SG #	Date	Amplitude [mm]	Preload Start [kN]	Preload End [kN]	Preload Loss %	Cycles run
14.2	15	17.11.21	±1,07	373,8	32,7	91,3 %	314

VIBRALOCK® Torqued M30							
Test #	SG #	Date	Amplitude [mm]	Preload Start [kN]	Preload End [kN]	Preload Loss %	Cycles run
16.0	12	17.11.21	±1,02	369,9	335,5	9,3 %	3025

Tensioning was prioritized over torquing because it is easier control the preload.
A few tests were run with torquing to prove the system for this as well. The strain gauges failed more often when the bolts were torqued as opposed to tensioned. Some strain gauge failures were expected.


TEST M30
VIBRALOCK®
HV BOLTS
PRELOAD [kN]
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
1
84
167
250
333
416
499
582
665
748
831
914
997
1080
1163
1246
1329
1412
1495
1578
1661
1744
1827
1910
1993
2076
2159
2242
2325
2408
2491
2574
2657
2740
2823
2906
2989
3072
3155
CYCLES
HV Tensioned M30 - Test 1.2
HV Tensioned M30 - Test 2.2
HV Tensioned M30 - Test 6.2
HV Tensioned M30 - Test 7.1
VIBRALOCK® Tensioned M30 - Test 3.0
VIBRALOCK® Tensioned M30 - Test 8.0
VIBRALOCK® Tensioned M30 - Test 9.0
VIBRALOCK® Tensioned M30 - Test 10.0
HV Torqued M30 - Test 14.2
VIBRALOCK® Torqued M30 - Test 16.0

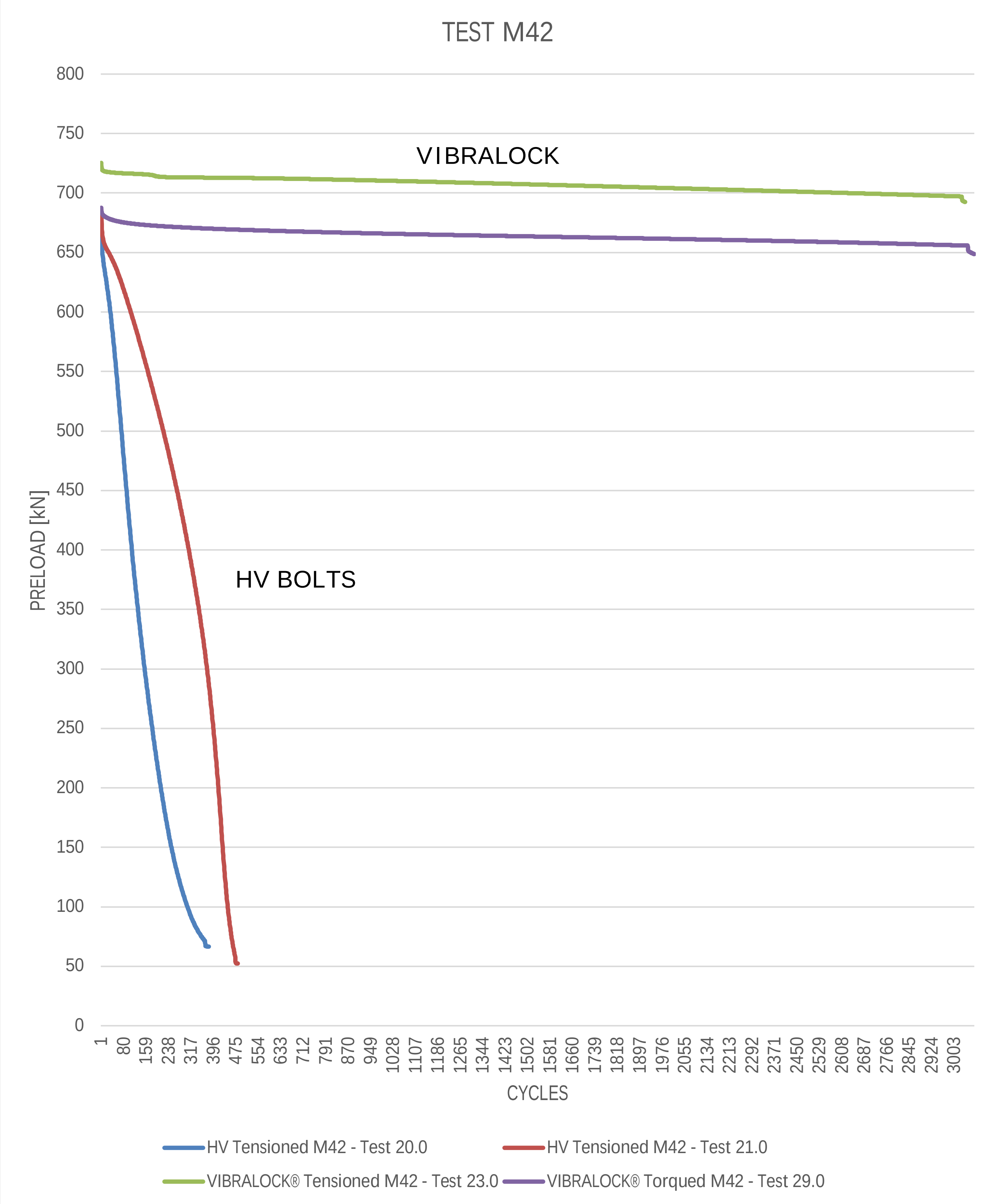
3.2 Results M42

HV Tensioned M42							
Test #	SG #	Date	Amplitude [mm]	Preload Start [kN]	Preload End [kN]	Preload Loss %	Cycles run
20.0	31	02.12.21	±1,34	676,3	67,0	90,1 %	367
21.0	33	02.12.21	±1,20	686,7	52,7	92,3 %	474

VIBRALOCK® Tensioned M42							
Test #	SG #	Date	Amplitude [mm]	Preload Start [kN]	Preload End [kN]	Preload Loss %	Cycles run
23.0	39	03.12.21	±1,02	725,5	694,1	4,3 %	3031

VIBRALOCK® Torqued M42							
Test #	SG #	Date	Amplitude [mm]	Preload Start [kN]	Preload End [kN]	Preload Loss %	Cycles run
29.0	30	06.12.21	±1,32	688,2	651,4	5,3 %	3052

Fewer bolts of M42 were tested due to time constraints and scheduling issues at test machine.
As shown in the graph below, the test results for M42 are still very determining.


TEST M42
VIBRALOCK
HV BOLTS
PRELOAD [kN]
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1
80
159
238
317
396
475
554
633
712
791
870
949
1028
1107
1186
1265
1344
1423
1502
1581
1660
1739
1818
1897
1976
2055
2134
2213
2292
2371
2450
2529
2608
2687
2766
2845
2924
3003
CYCLES
HV Tensioned M42 - Test 20.0
HV Tensioned M42 - Test 21.0
VIBRALOCK® Tensioned M42 - Test 23.0
VIBRALOCK® Torqued M42 - Test 29.0

4 Conclusion

The laboratory test shows that standard HV bolts experienced uniform loss of preload over the duration of the test with steady loosening of the nut. With the amplitudes specified, a loss of around 90% is obtained at between 200-400 cycles before the test is stopped to prevent surface damage to the test equipment.

For verification of the VIBRALOCK® system, the test was performed with similar amplitude and run for at least 3000 cycles to show the difference between the systems.

A loss of preload from 3,3% to 9,3% was measured by instrumentation after 3000 cycles. According to ISO 16130:2015 this is well within the limits of good self-locking behaviour.

No turning of the nut was detected on any of the VIBRALOCK® bolts for the duration of the test. In comparison, for the HV system, the nut started to turn almost immediately after starting the test. This was verified by video and markings on all parts. Video evidence available upon request.

All bolts were disassembled with the same tools used for installation, proving the simple removal process of the VIBRALOCK® system. Video evidence available upon request.

In conclusion, the VIBRALOCK® show an extreme resilience against loosening of the nut and loss of preload under severe transverse loading conditions while still being easy to remove if needed.