One dimensional consolidation test

Checking of compliance of the loading frame of a motorised automatic consolidation system

January 2024

This report was compiled by Ir. Prof. Philip WK Chung in collaboration with the technical team at the Public Works Central Laboratory, GEO, CEDD

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1. Requirements of GEOSPEC 3

Test 14.1 deals with the determination of compressibility characteristics of soils by the one-dimensional consolidation test. Clause 14.1.3 (f) stipulates the requirements of loading device and is extracted below:

> *"(1) The loading device shall be* **securely bolted** *onto the bench or supporting stand, which in turn shall be securely fixed to the floor or counterbalanced against overturning when fully loaded.*
> *(2) The device shall enable a vertical load to be* **applied axially** *in increments to the test specimen through a loading yoke. The load applied to the test specimen shall be central to the loading cap covering the top porous plate through a central seating. The loading mechanism shall be capable of* **applying the load immediately and without impact.**
> *(3) Calibrated hanger weights of a variety of combination shall be provided to enable the increments of load to be applied to the test specimen for achieving the required pressures. Each load increment shall be* **maintained constant** *by a stress-control method while permitting increasing vertical compression of the test specimen during the consolidation test. The vertical load applied to the specimen shall be* **capable of applying pressure to 2 kPa, and accurate to 4 kPa or 2% of the applied pressure***, whichever is greater. The apparatus shall be capable of accommodating a compression of* **at least 75%** *of the specimen thickness. A counterbalanced lever system, using calibrated weights in increments, is the method commonly employed for applying the vertical load to the test specimen."*

The key requirements are emphasized in the above excerpts. Specifically, there is a requirement that the loading mechanism must apply the load immediately. It is recommended that this provision be interpreted pragmatically. There must be some time lag between the load application from the device and the transfer of load to the soil specimen regardless of the type of equipment used. In the case of the typical counterbalanced lever system with screw control (refer to Fig 1), it may take approximately 1 to 2 seconds for the full transfer of the load. For most of the fine grained cohesive soils, e.g. marine deposits, alluvial clays etc, a 1-2 seconds of time lag induces negligible errors. For example, assume

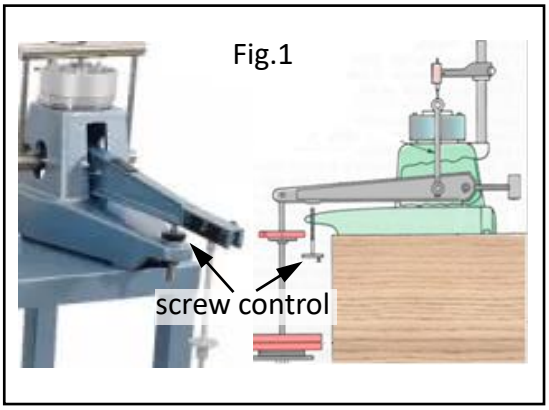


Fig.1

a coefficient of consolidation (c_v) equals 1 m^2/year which is a typical value for HK marine deposit, time for 50% and 90% average degree of consolidation (t_{90}) is shown below for a 19mm thick soil specimen:

Av. degree of consolidation	50%	90%
Time taken, i.e. t_{50} , t_{90}	9.3 min (558 s)	40 min (2400 s)

Therefore, a time lag of 1-2 seconds is considered acceptable.

2. Requirements of BS EN ISO 17892-5:2017

The title of this international standard is "Geotechnical investigation and testing — Laboratory testing of soil. Part 5: Incremental loading oedometer test. Clause 5.6 of this standard deals with the requirements of the loading frame and is extracted below:

> *"The loading frame shall allow the application of vertical stresses* **acting centrally on the loading cap** *only. The frame may apply load either by addition of physical weights, or by other mechanical, hydraulic, pneumatic or electromechanical means. The vertical stress applied to the specimen shall be* **accurate to at least 1 %** *of the intended stress* **or 1 kPa** *whichever is the greater. The stress shall* **remain constant** *within these limits throughout the duration of a loading increment. The mechanism should allow the application of a given load increment* **within a period of 2 s.**"

The key requirements are highlighted above. In this report, our focus will be on three areas as discussed in sections 4, 5, and 6 below.

3. Loading frame of the auto consolidation cell

The equipment being examined is the motorized automatic consolidation system "ACONS Pro" provided by VJ Tech Ltd. and currently utilized in the Public Works Central Laboratory (PWCL), as shown in Figure 2. The essential details provided by the supplier are outlined below:

Maximum load (kPa): 4000 kPa (for 70m dia. specimen)
Maximum Frame Capacity: 15 kN
Resolution: 0.1 N
Accuracy 0.15% FRO

Fig. 2

Adjustable Displacement Rate: 0.0001 - 10.0000 mm/min

The calibration certificate of the load cell used in this system is given in Appendix 1.

4. Checking of time period required for the application of load increment

The checking was conducted by applying the following loading, unloading, and reloading sequence to various metal discs and a ceramic clay sample (pottery clay, typically contains 70-80% SILT size and 20-30% CLAY size particles):

Unit: kPa

Seating	Loading						Unloading				Reloading	
5	12	25	50	100	200	400	200	100	50	25	400	800

As the top cap and top porous disc have already exerted a 1 kPa pressure on the soil specimen (refer to Fig 3), the actual loading applied will be as follows:

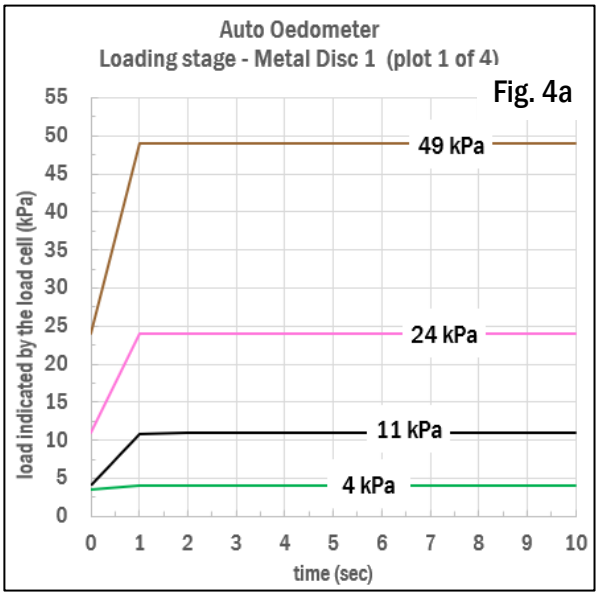
Unit: kPa

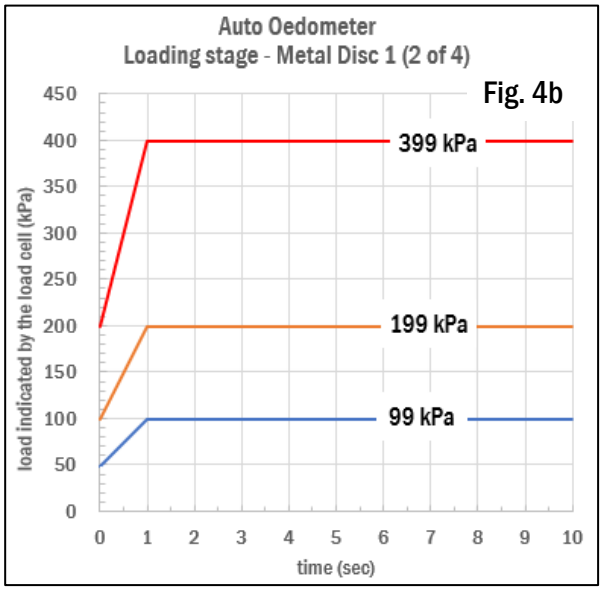
Seating	Loading						Unloading				Reloading	
4	11	24	49	99	199	399	199	99	49	24	399	799

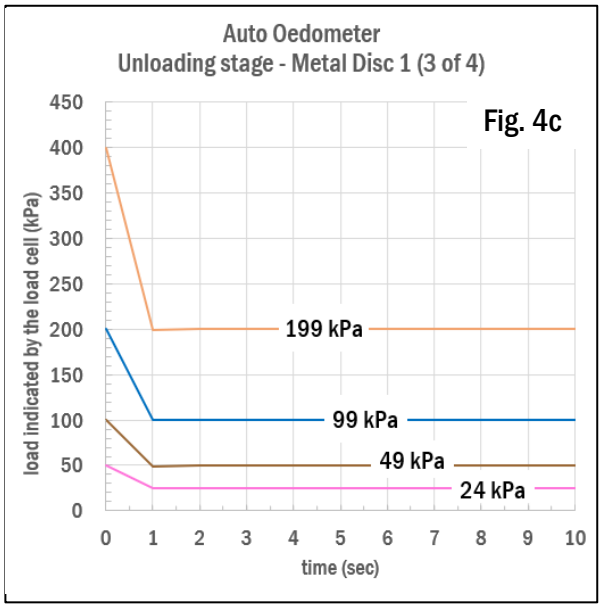
A metal disc and a ceramic clay were each used as dummy specimens in the checking process. For each specimen, time was recorded at 1-second intervals along with the magnitude of load as measured by the load cell. The 1-second interval is the shortest duration that can be measured by this apparatus. If a shorter duration, such as 0.5 seconds, is feasible for other similar apparatus, it should be utilized. The logging process was carried out for 10 seconds.

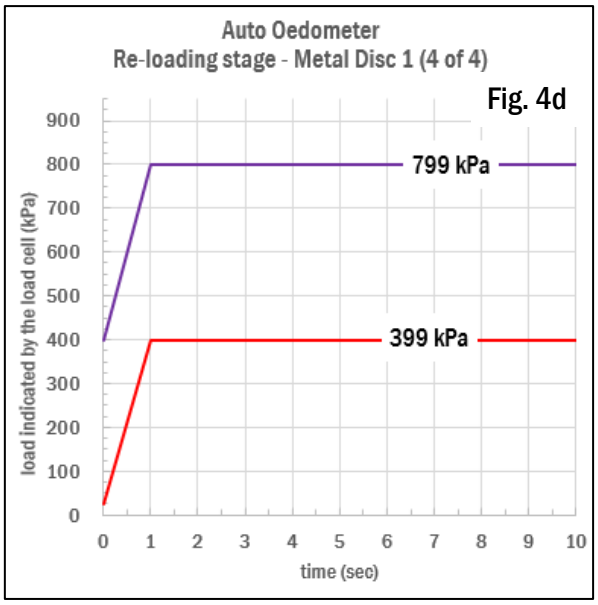
The results of load-time curves of the metal disc are shown in Fig. 4 below:

Fig. 3

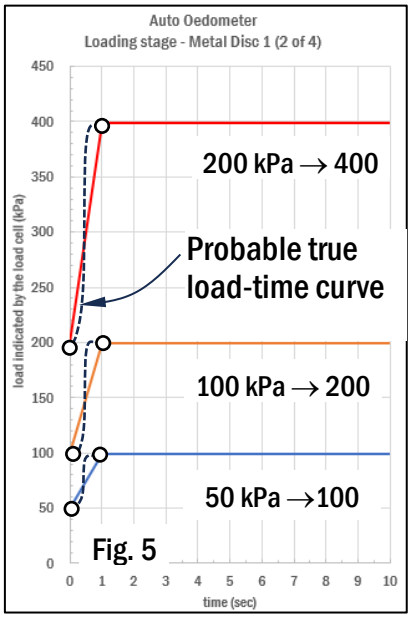






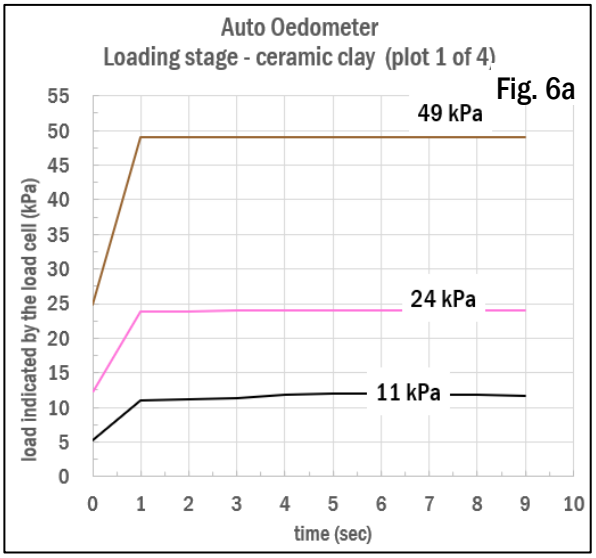


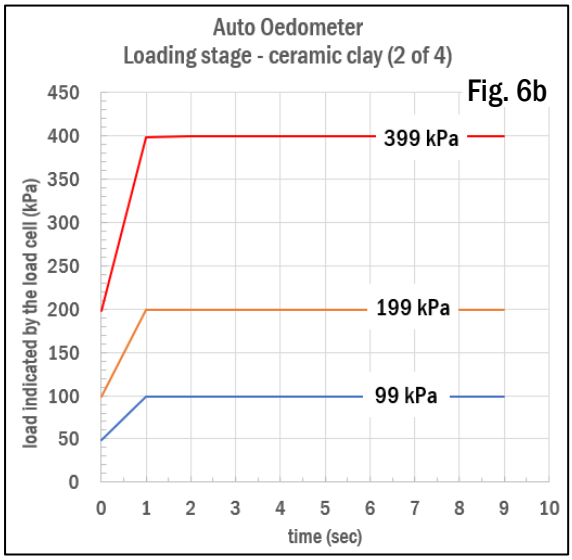
It is evident from Figure 4 that, regardless of the loading, unloading, and reloading phases, the load cell indicates complete load transfers within 2 seconds and hence satisfies the requirement as stipulated in BS EN ISO 17892-5:2017 . All load transfers were actually completed within 1 second. Considering the high rigidity of the metal disc and the apparatus's shortest measurement interval of 1 second, the likely accurate load-time curves are depicted in Figure 5, using 100 kPa, 200 kPa, and 400 kPa as examples.

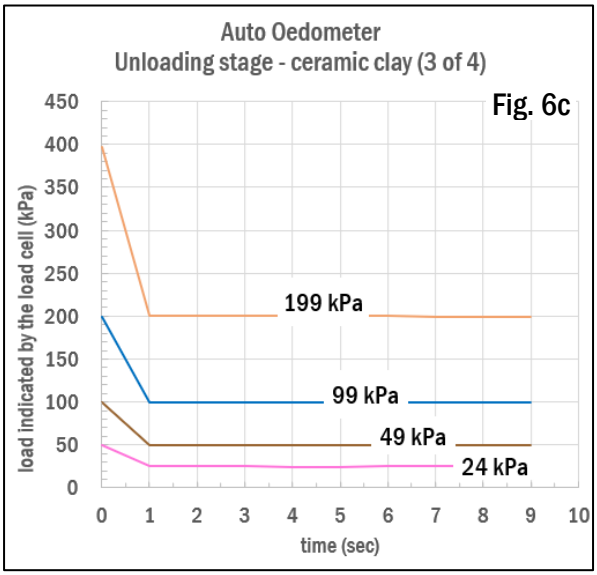


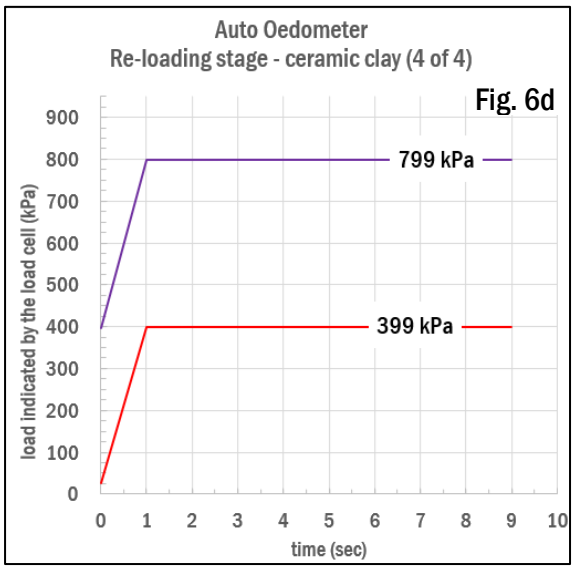
The load-time curves for ceramic clay are shown in Fig. 6.

It is evident from Figure 6 that, during the loading, unloading, and reloading phases, the load cell indicates complete load transfers within 2 seconds. Similar to the metal disc, all load transfers were accomplished within 1 second.









Given that the shortest measurement interval is only 1 second, it is hypothesized that the likely accurate load-time curves, as depicted in Figure 6, are analogous to those shown in Figure 5.

5. Checking of the stability of the load transfer

The traditional one-dimensional consolidation apparatus (oedometer) utilizes mechanical methods to apply and transfer loads to the soil samples. There are minimal concerns regarding the stability of load transfer in this setup With the use of stepper motor and

feedback control through proportional-integral-derivative (PID) or similar mechanism, it is advisable to also assess the stability of load transfer over time in each test. This is also one of the requirements of Geospec 3 and BS EN ISO 17892-5:2017 that the load transfer shall remain constant throughout the duration of a loading increment.

The applied load was maintained for 4 hours, and measurements were recorded to evaluate any notable drifts. We conducted measurements on a ceramic clay specimen for the loading, unloading, and reloading sequence outlined in Section 4. The results for one of the loading, unloading, and reloading phases are presented in the table below and depicted in Figure 7. Readings were captured at 1-second intervals. For clarity, only readings at selected time increments are displayed in the table below and in Figure 7.

Time		applie load (kPa)		
(sec)	(min)	24 -> 49	399 -> 199	24 ->399
6	0.1	48.88	200.02	398.54
30	0.5	48.94	199.78	398.81
60	1	48.95	199.87	398.83
300	5	48.98	199.72	398.92
600	10	48.00	199.91	398.97
3000	50	48.98	199.83	399.02
6000	100	48.99	199.95	399.02
14400	240	49.02	199.00	399.05

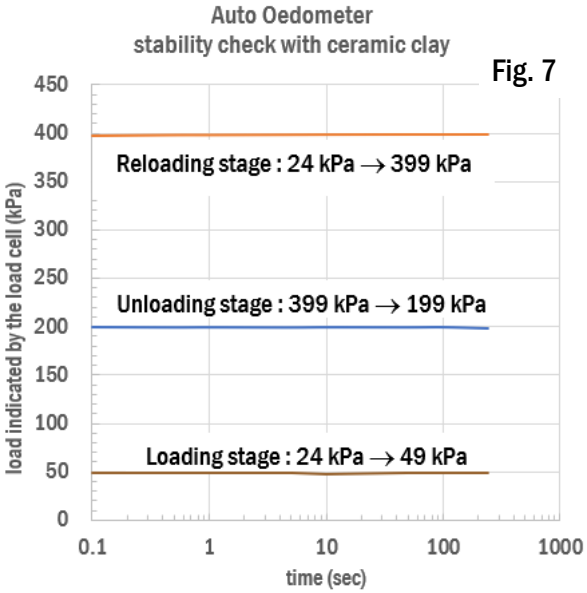


Fig. 7

Our evaluations indicated that the auto-oedometer can consistently sustain the applied loads for a minimum of 4 hours across all the loading-unloading-reloading sequences outlined in Section 4. Therefore, the load transfer system met the criteria specified in both Geospec 3 and BS EN ISO 17892-5:2017 regarding the duration of a loading increment lasting a minimum of 4 hours. From the trend of the measurements, the system should be able to provide a constant load transfer for a longer duration. If needed, further assessments can be conducted for longer durations, such as 6 hours or 12 hours.

6. Checking of the accuracy of the load cell

Geospec 3 requires that "*The vertical load applied to the specimen shall be capable of applying pressure to 2 kPa, and accurate to 4 kPa or 2% of the applied pressure, whichever is greater*." The requirement of BS EN ISO 17892-5:2017 is that "*The vertical stress applied to the specimen shall be accurate to at least 1 % of the intended stress or 1 kPa whichever is the greater.*"

Two reference load cells, CA0302 and CA0409, were employed in the verification process. The calibration certificates for these reference load cells are included in Appendix 2. One reference load cell covered the stress range from 0 kPa to approximately 1038 kPa, while the other reference load cell handled stress levels above 1038 kPa up to 2510 kPa. A single loading and unloading cycle was executed, and the outcomes are presented in the table below.

	Reference Load Cell		ACONS Pro		Difference (Reference - Measured)		
	(N)	(kPa)	(N)	(kPa)	(N)	(kPa)	(%)
Loading	0.0	0	0	0	0.0	0	0
	52.2	13.6	51.2	13.3	1.0	0.25	1.83
	154.0	40.0	152.1	39.5	1.9	0.48	1.21
	353.8	91.9	351.7	91.4	2.1	0.54	0.58
	761.9	198.0	760.1	197.5	1.8	0.48	0.24
	2361.2	613.6	2361.1	613.5	0.1	0.04	0.01
	3994.7	1038.0	3996.2	1038.4	-1.5	-0.39	-0.04
	5601.0	1455.4	5617.8	1459.8	-16.8	-4.38	-0.30
	7215.6	1874.9	7239.8	1881.2	-24.2	-6.29	-0.34
	8829.2	2294.2	8857.8	2301.7	-28.6	-7.44	-0.32
	9627.1	2501.6	9657.8	2509.5	-30.7	-7.97	-0.32
Unloading	8833.1	2295.2	8864.8	2303.5	-31.7	-8.24	-0.36
	7223.4	1877.0	7247.8	1883.3	-24.4	-6.33	-0.34
	5605.9	1456.7	5624.8	1461.6	-18.9	-4.92	-0.34
	3994.7	1038.0	3996.2	1038.4	-1.5	-0.39	-0.04
	2364.3	614.4	2363.0	614.0	1.3	0.35	0.06
	764.8	198.7	763.6	198.4	1.2	0.32	0.16
	355.7	92.4	354.9	92.2	0.8	0.20	0.22
	155.4	40.4	154.9	40.2	0.5	0.12	0.30
	53.3	13.8	53	13.8	0.3	0.07	0.48

The data in the table reveals that the vertical stresses exerted on the specimen were comfortably within ±1% of the target stress or ±1 kPa, whichever value is higher. Therefore, the load cell in the system meets the criteria outlined in both Geospec 3 and BS EN ISO 17892-5:2017.

Appendix 1 – Calibration Certificate of the Load Cell used in the Auto oedometer

Public Works Laboratories
Geotechnical Engineering Office, Hong Kong

CALIBRATION CERTIFICATE

Job	*N.A.*	Certificate No.	CL23000228
Customer/Customer address	*PTO/Lab 1, Public Works Central Laboratory Bldg., 1/F., 2B Cheung Yip St., Kowloon Bay, Kln.*	*Job/Contract No.*	*N.A.*
		Customer ref. No.	*N.A.*
Testing laboratory	PWCL Tel 2305 1286	Lab. file No.	STDCL-65-2085-1-3-1
Date test request	*18-Jan-23*	Date equipment received	N.A.
Date test commenced	19-Jan-23	Date test completed	19-Jan-23
Test Request No.	CLCAL 2300095		

Scope of test : Load verification of uniaxial testing machine, using true force method, in compression to BS EN ISO 7500-1:2004

Details of uniaxial testing machine :

Type	*Load cell*	*Nominal capacity*	*15 kN*
Equipment I.D. No.	*SR1796*	*Force measuring system*	*Computer logging system*
Manufacturer	*N.A.*	*Resolution, r*	*0.1 N*
Model No.	*VJT0650M-P*	*Range verified*	*0.05 - 14.9 kN*
Serial No.	*0541917*		

Test results:

Force (N)	Mean indicated force (N)	Relative Repeatability error (%)	Relative accuracy error (%)	Relative Resolution (%)	Expanded uncertainty (%)	Expanded uncertainty (N)
50	49.80	1.0	-0.40	0.2	0.65	0.33
75	74.60	0.8	-0.53	0.1	0.51	0.38
150	149.00	0.3	-0.67	0.1	0.32	0.48
500	499.7	0.1	-0.06	0.0	0.32	1.6
750	749.7	0.1	-0.04	0.0	0.33	2.5
1500	1501.8	0.1	0.12	0.0	0.34	5.0
3000	3007.7	0.1	0.26	0.0	0.33	9.9
6000	5992	0.3	-0.13	0.0	0.36	22
9000	8992	0.2	-0.09	0.0	0.35	31
12000	11998	0.2	-0.02	0.0	0.34	41
14900	14903	0.2	0.02	0.0	0.34	51

Remarks:

1. The uniaxial testing machine has been verified by comparison with the force-proving instrument(s) of Equipment I.D. No. CA0412, CA0256 and CA0280 which are traceable to internationally recognised primary standards.
2. The force-proving instrument(s) information:

Equipment I.D.	Type	Calibration certificate no.	Class	Range	Expire date
CA0412	Load cell	203621F	0.5	0.5 kN to 0.05 kN	24-Jul-23
CA0256	Load cell	LCL202103361	1	5 kN to 0.5 kN	10-Sep-23
CA0280	Load cell	LCL202100579	1	20 kN to 2 kN	6-Feb-23

3. Relative zero force error is within ± 0.1%.
4. Verification was carried out at the piston position around the normal operating range. The uniaxial testing machine is not equipped with maximum reading facility. Determination of relative reversibility was not carried out in this verification.
5. Temperature during verification was 20.9 ± 2 °C.
6. Verification was passed to reach agreement between the two force-proving instruments at 3000 N and 500 N.
7. Verification was carried out in PWCL - Lab 1.
8. The testing machine was verified in the 'as found' condition with no adjustments carried out.
9. The reported expanded measurement uncertainty is stated as the standard measurement uncertainty multiplied by the coverage factor k such that the coverage probability corresponds to approximately 95%.
10. According to BS EN ISO 7500-1:2004, the classification of the uniaxial testing machine is Class 1 from 14900 N to 50 N.

-END-

Checked by		Certified by	
Name	Ng Ka Wai	Name	Kwok Hei Mui
Post	STO/Lab.(Atg.)	Post	PTO/Lab.
Date	20-Jan-23	Date	20-Jan-23

Original

Public Works Central Laboratory, Public Works Central Laboratory Building, 2B Cheung Yip St., Kowloon Bay, Kowloon
PWL CAL 1.1(a)C Oct 2022
C Eng D (GEO) 2053 Oct 2020

Appendix 2 – Calibration certificates of two reference load cells (CA0302 and CA0409)

(CA0409)

华南国家计量测试中心
广东省计量科学研究院
SOUTH CHINA NATIONAL CENTER OF METROLOGY
GUANGDONG INSTITUTE OF METROLOGY

中国认可 国际互认 校准 CALIBRATION CNAS L0730

校 准 证 书
CALIBRATION CERTIFICATE

证书编号 Certificate No. LCL202302899　　第 1 页，共 7 页 Page of

委托方 Client	Civil Engineering and Development Department, Public Works Central Laboratory
委托方联络信息 Contact Information	Rm G31, G/F., PWCL Bldg., 2B Cheung Yip Street, Kowloon Bay, Kln., Hong Kong
计量器具名称 Description	Load Cell
型号/规格 Model/Type	DBBSEHM-500kg-003-000
制造厂 Manufacturer	Applied Measurement Ltd.
出厂编号 Serial No.	70819　　设备管理编号 Equipment No. CA0409
接收日期 Date of Receipt	2023 年 Y 05 月 M 15 日 D
结果 Results	见校准结果 Shown in the results of calibration
校准日期 Date of Calibration	2023 年 Y 06 月 M 06 日 D

批 准 人 Approved Signatory 王叶斌

核　验 Reviewed by 朱连宇

校　准 Calibrated by 廖嘉文

证书专用章 Stamp

扫一扫查真伪

本中心地址：中国广州市广园中路松柏东街30号　　邮政编码：510405
电话：(8620)86594172 传真：(8620)86590743 投诉电话：(8620)36611242 E-mail：scm@scm.com.cn
Add: No.30, Songbai East Street, Guangyuan Middle Road, Guangzhou, Guangdong, China
Post Code: 510405 Tel: (8620)86594172 Fax: (8620)86590743 Complaint Tel: (8620)36611242
证书真伪查询：www.scm.com.cn；cert.scm.com.cn Certificate AuthenticityIdentify: www.scm.com.cn; cert.scm.com.cn

H44840 2

说　明

证书编号 LCL202302899
Certificate No.

DIRECTIONS

1. 本中心是国家市场监督管理总局在华南地区设立的国家法定计量检定机构，本中心的质量管理体系符合ISO/IEC 17025:2017标准的要求。
This laboratory is the National Legal Metrological Verification Institution in southern China set up by the State Administration for Market Regulation. The quality system is in accordance with ISO/IEC 17025:2017.

2. 本中心所出具的数据均可溯源至国家计量基准和/或国际单位制(SI)。
All data issued by this laboratory are traceable to national primary standards and/or International System of Units (SI).

3. 校准地点、环境条件：
Place and environmental conditions of the calibration:

地点 Place	本中心测力实验室 Dynamometry Lab	温度 Temperature	23.7 ℃	相对湿度 R.H.	51 %

4. 本次校准的技术依据：
Reference documents for the calibration:
ISO 376-2011 金属材料 单轴向试验机验证用样品和试件用作用力检验仪的校准 Metallic materials. Calibration of force-proving instruments used for the verification of uniaxial testing machines

5. 本次校准所使用的主要计量标准器具：
Major standards of measurement used in the calibration:

设备名称/型号规格/测量范围 Name of Equipment /Model/Type/Range	编号 Serial No.	证书号/有效期/溯源单位 Certificate No./Due Date /Traceability to	计量特性 Metrological Characteristic
静重式力标准机 Deadweight Force Standard Machine /CX-J10/(0.1~10)kN	1407094	检定字第202206008425号 /2024-06-26 /国家计量院	0.01级 Grade 0.01

注：1. 本证书校准结果只与受校准仪器有关。The results relate only to the items calibrated.
Note: 2. 未经本机构书面批准，不得部分复制此证书。This certificate shall not be reproduced except in full, without the written approval of our laboratory.
3. “委托方”、“委托方联络信息”由委托方提供，“制造厂”、“型号规格”、“出厂编号”以及“设备编号”为仪器上标注，委托方对上面内容如有异议，须在收到证书后二十个工作日内提出。
The information **Client** and **Contact Information** are provided by client, and the **Manufacturer**, **Model/Type**, **Serial No.** and **Equipment No.** are marked on the items. Client shall submit any objection within 20 working days after receiving the certificate for the information above.
4. 本次校准日期视为发布日期。The calibration date is the date of issue of the certificate.

校 准 结 果
RESULTS OF CALIBRATION

证书编号 LCL202302899 Certificate No.　　原始记录号 LCL202302899 Record No.　　第 3 页,共 7 页 Page of

I. 压向（Compression）

1. 力值测试(Force test)：

测试结果见表1(The results of test are shown in table 1.)

表1 力值压向

Table1 Compression

序号(S/N)	R1	R2	R3	R4	R3'	R4'	平均值Average (kN)	
方位(Positions)	0°	0°	120°	240°	120°	240°		
标准力值 (kN)Standard Force	示　值Indication (kN)						进程 Increasing	回程 Decreasing
0.5	0.4993	0.4990	0.4991	0.4998	0.4994	0.5004	0.4994	0.4998
1.0	0.9987	0.9985	0.9985	0.9988	1.0003	1.0005	0.9987	1.0004
1.5	1.4983	1.4981	1.4982	1.4985	1.4986	1.5007	1.4983	1.4996
2.0	1.9980	1.9977	1.9979	1.9982	1.9993	2.0006	1.9980	1.9999
2.5	2.4980	2.4978	2.4978	2.4982	2.5000	2.5005	2.4980	2.5002
3.0	2.9978	2.9976	2.9977	2.9979	3.0002	3.0003	2.9978	3.0002
3.5	3.4978	3.4976	3.4976	3.4979	3.4985	3.5001	3.4978	3.4994
4.0	3.9978	3.9976	3.9978	3.9980	3.9991	3.9995	3.9979	3.9993
4.5	4.4979	4.4978	4.4977	4.4982	4.4994	4.4991	4.4979	4.4992
5.0	4.9981	4.9979	4.9979	4.9973	----	----	4.9978	----

表1说明(Note)：

(1)所列示值为修正零位后的示值。

The indications in the table are on the condition that zero error is corrected.

(2)序列R1、R2、R3、R4为进程力示值，序列R3'、R4'为回程力示值。

Measuring series R1, R2, R3, R4 were readings at increasing force， Measuring series R3', R4' were readings at decreasing force.

(3)平均值计算：加荷时，计算R1、R3、R4列测试数据的平均值；卸荷时，计算R3'、R4'列测试数据的滞后偏差并求出其平均偏差值，再以之修正相应载荷点加荷时的平均值。

Calculating average: when load is increasing, calculate the averages of data of column R1 , column R3 and column R4; calculate the reversibility error of data of column R3' and column R4',and then calculate the averages, finally according as them ,correct the averages that correspond to the loading points when loading is increasing;

校 准 结 果
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2. 插值公式(Formula of interpolation)：

根据表1测试数据表达如下(According to the results of test shown in table 1)：

F— 力值(Force)，kN;

D— 指示装置示值 (Indication)，kN;

2.1 $F=a_1+a_2D+a_3D^2$

式中(where)：

a_1= 0.00028078

a_2= 1.00108

a_3= -0.000145574

2.2 $D=b_1+b_2F+b_3F^2$

式中(where)：

b_1= -0.00028

b_2= 0.998924

b_3= 0.000145455

3. 校准结果(Result of calibration)：

项目	标准测力仪的最大相对误差 Maximum relative error of the force-proving instrument				
	复现性 reproducibility b	重复性 repeatability b'	插值 interpolation f_c	零点 zero f_0	进回程 reversibility v
(%)	0.14	0.06	+0.040	+0.006	0.18

校 准 结 果
RESULTS OF CALIBRATION

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II. 拉向（Tension）

1. 力值测试(Force test)：

测试结果见表2(The results of test are shown in table 2.)

表2 力值拉向

Table2 Tension

序号(S/N)	R1	R2	R3	R4	R3'	R4'	平均值Average (kN)	
方位(Positions)	0°	0°	120°	240°	120°	240°		
标准力值 (kN)Standard Force	示 值Indication (kN)						进程 Increasing	回程 Decreasing
0.5	-0.4993	-0.4994	-0.4996	-0.5001	-0.5009	-0.5016	-0.4997	-0.5011
1.0	-0.9988	-0.9989	-0.9991	-0.9997	-1.0010	-1.0017	-0.9992	-1.0012
1.5	-1.4985	-1.4985	-1.4989	-1.4995	-1.5013	-1.5018	-1.4990	-1.5014
2.0	-1.9983	-1.9985	-1.9987	-1.9994	-2.0015	-2.0019	-1.9988	-2.0014
2.5	-2.4983	-2.4986	-2.4987	-2.4993	-2.5013	-2.5020	-2.4988	-2.5014
3.0	-2.9982	-2.9984	-2.9988	-2.9994	-3.0012	-3.0019	-2.9988	-3.0012
3.5	-3.4985	-3.4986	-3.4988	-3.4995	-3.5011	-3.5018	-3.4989	-3.5012
4.0	-3.9986	-3.9985	-3.9992	-3.9997	-4.0007	-4.0015	-3.9992	-4.0008
4.5	-4.4990	-4.4993	-4.4994	-4.5002	-4.5003	-4.5011	-4.4995	-4.5004
5.0	-4.9993	-4.9996	-4.9998	-5.0005	----	----	-4.9999	----

表2说明(Note)：

(1)所列示值为修正零位后的示值。

The indications in the table are on the condition that zero error is corrected.

(2)序列R1、R2、R3、R4为进程力示值，序列R3'、R4'为回程力示值。

Measuring series R1, R2, R3, R4 were readings at increasing force， Measuring series R3', R4' were readings at decreasing force.

(3)平均值计算：加荷时，计算R1、R3、R4列测试数据的平均值；卸荷时，计算R3'、R4'列测试数据的滞后偏差并求出其平均偏差值，再以之修正相应载荷点加荷时的平均值。

Calculating average: when load is increasing, calculate the averages of data of column R1 , column R3 and column R4; calculate the reversibility error of data of column R3' and column R4',and then calculate the averages, finally according as them ,correct the averages that correspond to the loading points when loading is increasing;

校 准 结 果
RESULTS OF CALIBRATION

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2. 插值公式(Formula of interpolation):

根据表2测试数据表达如下(According to the results of test shown in table 2):

F— 力值(Force), kN;

D— 指示装置示值 (Indication), kN;

2.1 $F=a_1+a_2D+a_3D^2$

式中(where):

a_1= -0.000114243

a_2= -1.00104

a_3= -0.000201476

2.2 $D=b_1+b_2F+b_3F^2$

式中(where):

b_1= -0.000115

b_2= -0.998955

b_3= -0.000201515

3. 校准结果(Result of calibration):

项目	标准测力仪的最大相对误差 Maximum relative error of the force-proving instrument				
	复现性 reproducibility b	重复性 repeatability b'	插值 interpolation f_c	零点 zero f_0	进回程 reversibility v
(%)	0.16	0.02	+0.020	-0.004	0.28

说明:

Note:

1. 结果:以上校准结果符合 ISO376-2011 (准确度1级) 技术要求。

Results:The data of instrument calibrated above comply with the technical characteristics in ISO376-2011 (for accuracy Class 1).

按ISO376-2011压向定级如下(According to ISO376 -2011 for compression):

情况B:以规定的力和递增/递减力分级。

Case B: For instruments classified only for specific forces and incremental/decremental loading.

(0.5~ 5) kN: 1级 (Class 1)

情况D:以插值和递增/递减力分级。

Case D: For instruments classified for interpolation and incremental/decremental loading.

(0.5~5) kN: 1级 (Class 1)

按ISO376-2011拉向定级如下(According to ISO376 -2011 for tension):

校 准 结 果
RESULTS OF CALIBRATION

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情况B：以规定的力和递增/递减力分级。

Case B: For instruments classified only for specific forces and incremental/decremental loading.

(0.5 ~5) kN：1级 (Class 1)

情况D：以插值和递增/递减力分级。

Case D: For instruments classified for interpolation and incremental/decremental loading.

(0.5~5) kN：1级 (Class 1)

校准结果符合性判定依据JJF1094-2002《测量仪器特性评定》之5.3.1和ISO376-2011《金属材料 单轴试验机检验用标准测力仪的校准》。

Decision rules of conformity are JJF1094-2002 *Evaluation of the Characteristics of Measuring Instruments* (5.3.1) and ISO376-2011 *Metallic materials. Calibration of force-proving instruments used for the verification of uniaxial testing machines*.

2. 本次测量结果扩展不确定度：力值 U_{rel} =0.12%，包含因子 k =2.

Expanded uncertainty of measuring results: Force U_{rel} =0.12%, Coverage factor k =2.

本证书中给出的扩展不确定度依据JJF1059.1-2012《测量不确定度评定与表示》评定，由合成标准不确定度乘以包含概率约为95%时对应的包含因子 k 得到。

The expanded uncertainty given in this certificate is evaluated according to JJF 1059.1-2012 Evaluation and Expression of Uncertainty in Measurement, which is obtained by multiplying the combined standard uncertainty by the coverage factor k corresponding to the coverage probability of about 95%.

该传感器及其指示装置作为整体一起测试。测试前，在实验室环境条件下恒温24小时以上，并预热超过30分钟。

The load cell and the indicator are tested as one whole. Before the test,the instrument shall be laid in the laboratory condition with a stable temperature over 24 hours, and warm-up 30 minutes.

3. 按照所依据技术文件的规定，建议复校时间间隔不超过1年。

更换重要部件、维修或对仪器性能有怀疑时，应及时校准。

According to the demand of reference document, next calibration is proposed within 1 year.

In case of replacement of important parts, maintenance or doubt on the performance of the instrument,it shall be calibrated in time.

4.指示装置型号：TR150；指示装置编号：17479271；压向通道：CH1；拉向通道：CH2。

Indicator Model: TR150; Indicator S/N: 17479271; Channel of Compression: CH1; Channel of Tension: CH2.

Appendix 2 – Calibration certificates of two reference load cells (CA0302 and CA0409)

(CA0302)

华南国家计量测试中心
广东省计量科学研究院
SOUTH CHINA NATIONAL CENTER OF METROLOGY
GUANGDONG INSTITUTE OF METROLOGY

中国认可 国际互认 校准 CALIBRATION CNAS L0730

校 准 证 书
CALIBRATION CERTIFICATE

证书编号 Certificate No. LCL202204436

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委托方 Client	Civil Engineering and Development Department, Public Works Central Laboratory
委托方联络信息 Contact Information	Rm G31, G/F., PWCL Bldg., 2B Cheung Yip Street, Kowloon Bay, Kln., Hong Kong
计量器具名称 Description	Load Cell
型号/规格 Model/Type	DBBW-2T/TR150
制造厂 Manufacturer	---
出厂编号 Serial No.	50695455/16818790
设备管理编号 Equipment No.	CA0302
接收日期 Date of Receipt	2022 年 Y 11 月 M 14 日 D
结果 Results	见校准结果 Shown in the results of calibration
校准日期 Date of Calibration	2022 年 Y 12 月 M 22 日 D

批 准 人 Approved Signatory 谭洪辉

核 验 Reviewed by 黄振江

校 准 Calibrated by 蔡志强

证书专用章 Stamp

扫一扫查真伪

本中心地址：中国广州市广园中路松柏东街30号 邮政编码：510405
电话：(8620)86594172 传真：(8620)86590743 投诉电话：(8620)36611242 E-mail：scm@scm.com.cn
Add: No.30, Songbai East Street, Guangyuan Middle Road, Guangzhou, Guangdong, China
Post Code: 510405 Tel: (8620)86594172 Fax: (8620)86590743 Complaint Tel: (8620)36611242
证书真伪查询：www.scm.com.cn；cert.scm.com.cn Certificate AuthenticityIdentify: www.scm.com.cn; cert.scm.com.cn

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说　明

证书编号 LCL202204436
Certificate No.

DIRECTIONS

1. 本中心是国家市场监督管理总局在华南地区设立的国家法定计量检定机构，本中心的质量管理体系符合ISO/IEC 17025:2017标准的要求。
   This laboratory is the National Legal Metrological Verification Institution in southern China set up by the State Administration for Market Regulation. The quality system is in accordance with ISO/IEC 17025:2017.

2. 本中心所出具的数据均可溯源至国家计量基准和/或国际单位制(SI)。
   All data issued by this laboratory are traceable to national primary standards and/or International System of Units (SI).

3. 校准地点、环境条件：
   Place and environmental conditions of the calibration:

地点 Place	本中心测力实验室 Dynamometry Lab	温度 Temperature	23.0 ℃	相对湿度 R.H.	60 %

4. 本次校准的技术依据：
   Reference documents for the calibration:
   ISO 376-2011 金属材料 单轴向试验机验证用样品和试件用作用力检验仪的校准 Metallic materials. Calibration of force-proving instruments used for the verification of uniaxial testing machines

5. 本次校准所使用的主要计量标准器具：
   Major standards of measurement used in the calibration:

设备名称/型号规格 Name of Equipment /Model/Type	编号 Serial No.	证书号/有效期/溯源单位 Certificate No./Due Date /Traceability to	计量特性 Metrological Characteristic
杠杆式力标准机 Lever-amplification Force Standard Machi /EJⅡ-6	2C6-5	LSfm2021-11674 /2023-04-08 /国家计量院	0.03级；力值重复性≤0.01% Grade 0.03; Repeatability≤0.01%

注：1. 本证书校准结果只与受校准仪器有关。The results relate only to the items calibrated.
Note: 2. 未经本机构书面批准，不得部分复制此证书。This certificate shall not be reproduced except in full, without the written approval of our laboratory.
3. “委托方”、“委托方联络信息”由委托方提供，“制造厂”、“型号规格”、“出厂编号”以及“设备编号”为仪器上标注，委托方对上面内容如有异议，须在收到证书后二十个工作日内提出。
The information **Client** and **Contact Information** are provided by client, and the **Manufacturer**, **Model/Type**, **Serial No.** and **Equipment No.** are marked on the items. Client shall submit any objection within 20 working days after receiving the certificate for the information above.
4. 本次校准日期视为发布日期。The calibration date is the date of issue of the certificate.

校 准 结 果
RESULTS OF CALIBRATION

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I. 拉向（Tension）

1. 力值测试(Force test)：

测试结果见表1(The results of test are shown in table 1.)

表1 力值拉向

Table1 Tension

序号(S/N)	R1	R2	R3	R4	R3'	R4'	平均值Average (div.)	
方位(Positions)	0°	0°	120°	240°	120°	240°		
标准力值 (kN)Standard Force	示 值Indication (div.)						进程 Increasing	回程 Decreasing
2	0.2037	0.2037	0.2037	0.2036	0.2039	0.2038	0.2037	0.2039
4	0.4076	0.4074	0.4075	0.4074	0.4079	0.4077	0.4075	0.4078
6	0.6114	0.6112	0.6113	0.6113	0.6117	0.6116	0.6113	0.6116
8	0.8152	0.8151	0.8152	0.8151	0.8157	0.8154	0.8152	0.8156
10	1.0192	1.0190	1.0191	1.0191	1.0196	1.0194	1.0191	1.0195
12	1.2230	1.2229	1.2230	1.2229	1.2235	1.2232	1.2230	1.2234
14	1.4268	1.4269	1.4269	1.4269	1.4274	1.4272	1.4269	1.4273
16	1.6312	1.6310	1.6311	1.6308	1.6315	1.6311	1.6310	1.6314
18	1.8350	1.8350	1.8350	1.8349	1.8352	1.8351	1.8350	1.8352
20	2.0392	2.0390	2.0391	2.0388	----	----	2.0390	----

表1说明(Note)：

(1)所列示值为修正零位后的示值。

The indications in the table are on the condition that zero error is corrected.

(2)序列R1、R2、R3、R4为进程力示值，序列R3'、R4'为回程力示值。

Measuring series R1, R2, R3, R4 were readings at increasing force， Measuring series R3', R4' were readings at decreasing force.

(3)平均值计算：加荷时，计算R1、R3、R4列测试数据的平均值；卸荷时，计算R3'、R4'列测试数据的滞后偏差并求出其平均偏差值，再以之修正相应载荷点加荷时的平均值。

Calculating average: when load is increasing, calculate the averages of data of column R1 , column R3 and column R4; calculate the reversibility error of data of column R3' and column R4',and then calculate the averages, finally according as them ,correct the averages that correspond to the loading points when loading is increasing;

校 准 结 果
RESULTS OF CALIBRATION

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2. 插值公式(Formula of interpolation)：

根据表1测试数据表达如下(According to the results of test shown in table 1)：

F— 力值(Force)，kN;

D— 指示装置示值 (Indication)，div.;

2.1 $F=a_1+a_2D+a_3D^2$

式中(where)：

a_1= 0.000689171

a_2= 9.81592

a_3= -0.00375205

2.2 $D=b_1+b_2F+b_3F^2$

式中(where)：

b_1= -0.00007

b_2= 0.101875

b_3= 3.97727E-06

3. 校准结果(Result of calibration)：

项目	标准测力仪的最大相对误差 Maximum relative error of the force-proving instrument				
	复现性 reproducibility b	重复性 repeatability b'	插值 interpolation f_c	零点 zero f_0	进回程 reversibility v
(%)	0.05	0.05	-0.010	0.000	0.10

校 准 结 果
RESULTS OF CALIBRATION

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II. 压向（Compression）

1. 力值测试(Force test)：

测试结果见表2(The results of test are shown in table 2.)

表2 力值压向

Table2 Compression

序号(S/N)	R1	R2	R3	R4	R3'	R4'	平均值Average (div.)	
方位(Positions)	0°	0°	120°	240°	120°	240°		
标准力值 (kN)Standard Force	示 值Indication (div.)						进程 Increasing	回程 Decreasing
2	0.2037	0.2037	0.2037	0.2037	0.2038	0.2038	0.2037	0.2038
4	0.4074	0.4073	0.4074	0.4073	0.4076	0.4075	0.4074	0.4076
6	0.6111	0.6110	0.6111	0.6110	0.6113	0.6111	0.6111	0.6112
8	0.8150	0.8149	0.8150	0.8149	0.8152	0.8150	0.8150	0.8152
10	1.0187	1.0186	1.0187	1.0188	1.0190	1.0190	1.0187	1.0190
12	1.2225	1.2224	1.2225	1.2225	1.2229	1.2226	1.2225	1.2228
14	1.4264	1.4262	1.4263	1.4262	1.4265	1.4263	1.4263	1.4264
16	1.6301	1.6303	1.6302	1.6300	1.6304	1.6301	1.6301	1.6302
18	1.8338	1.8340	1.8339	1.8337	1.8341	1.8339	1.8338	1.8340
20	2.0377	2.0378	2.0378	2.0376	----	----	2.0377	----

表2说明(Note)：

(1)所列示值为修正零位后的示值。

The indications in the table are on the condition that zero error is corrected.

(2)序列R1、R2、R3、R4为进程力示值，序列R3'、R4'为回程力示值。

Measuring series R1, R2, R3, R4 were readings at increasing force， Measuring series R3', R4' were readings at decreasing force.

(3)平均值计算：加荷时，计算R1、R3、R4列测试数据的平均值；卸荷时，计算R3'、R4'列测试数据的滞后偏差并求出其平均偏差值，再以之修正相应载荷点加荷时的平均值。

Calculating average: when load is increasing, calculate the averages of data of column R1 , column R3 and column R4; calculate the reversibility error of data of column R3' and column R4',and then calculate the averages, finally according as them ,correct the averages that correspond to the loading points when loading is increasing;

校 准 结 果
RESULTS OF CALIBRATION

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2. 插值公式(Formula of interpolation)：

根据表2测试数据表达如下(According to the results of test shown in table 2)：

F— 力值(Force)，kN;

D— 指示装置示值 (Indication)，div.;

2.1 $F=a_1+a_2D+a_3D^2$

式中(where)：

a_1= 0.000769116

a_2= 9.81637

a_3= -0.000805719

2.2 $D=b_1+b_2F+b_3F^2$

式中(where)：

b_1= -7.83333E-05

b_2= 0.101871

b_3= 8.52273E-07

3. 校准结果(Result of calibration)：

项目	标准测力仪的最大相对误差 Maximum relative error of the force-proving instrument				
	复现性 reproducibility b	重复性 repeatability b'	插值 interpolation f_c	零点 zero f_0	进回程 reversibility v
(%)	0.03	0.03	-0.020	0.000	0.05

说明：

Note：

1．结果：以上校准结果符合 ISO376-2011 (准确度1级) 技术要求。

Results:The data of instrument calibrated above comply with the technical characteristics in ISO376-2011 (for accuracy Class 1).

按ISO376-2011拉向定级如下(According to ISO376 -2011 for tension)：

情况B：以规定的力和递增/递减力分级。

Case B: For instruments classified only for specific forces and incremental/decremental loading.

(2~ 20) kN：1级 (Class 1)

情况D：以插值和递增/递减力分级。

Case D: For instruments classified for interpolation and incremental/decremental loading.

(2~20) kN：1级 (Class 1)

按ISO376-2011压向定级如下(According to ISO376 -2011 for compression)：

校 准 结 果
RESULTS OF CALIBRATION

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情况B：以规定的力和递增/递减力分级。

Case B: For instruments classified only for specific forces and incremental/decremental loading.

(2~20) kN：1级 (Class 1)

情况D：以插值和递增/递减力分级。

Case D: For instruments classified for interpolation and incremental/decremental loading.

(2~ 20) kN：1级 (Class 1)

校准结果符合性判定依据JJF1094-2002《测量仪器特性评定》之5.3.1和ISO376-2011《金属材料 单轴试验机检验用标准测力仪的校准》。

Decision rules of conformity are JJF1094-2002 *Evaluation of the Characteristics of Measuring Instruments* (5.3.1) and ISO376-2011 *Metallic materials. Calibration of force-proving instruments used for the verification of uniaxial testing machines*.

2. 本次测量结果扩展不确定度：力值 U_{rel} =0.09%，包含因子 k =2.

Expanded uncertainty of measuring results: Force U_{rel} =0.09%, Coverage factor k =2.

本证书中给出的扩展不确定度依据JJF1059.1-2012《测量不确定度评定与表示》评定，由合成标准不确定度乘以包含概率约为95%时对应的包含因子 k 得到。

The expanded uncertainty given in this certificate is evaluated according to JJF 1059.1-2012 Evaluation and Expression of Uncertainty in Measurement, which is obtained by multiplying the combined standard uncertainty by the coverage factor k corresponding to the coverage probability of about 95%.

该传感器及其指示装置作为整体一起测试。测试前，在实验室环境条件下恒温24小时以上，并预热超过30分钟。

The load cell and the indicator are tested as one whole. Before the test,the instrument shall be laid in the laboratory condition with a stable temperature over 24 hours, and warm-up 30 minutes.

3. 按照所依据技术文件的规定，建议复校时间间隔不超过1年。

更换重要部件、维修或对仪器性能有怀疑时，应及时校准。

According to the demand of reference document, next calibration is proposed within 1 year.

In case of replacement of important parts, maintenance or doubt on the performance of the instrument,it shall be calibrated in time.