PRESSURE MEASUREMENT

INTERLABORATORY COMPARISON
APLAC M025

Final Report

November 2012

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CONTENTS

1. INTRODUCTION

This report summarises the results of an interlaboratory comparison on pressure calibration by laboratories accredited by bodies that are members of the Asia Pacific Laboratory Accreditation Cooperation (APLAC). The identification code number of this programme is M025. This programme was coordinated by Department of Standards Malaysia (STANDARDS MALAYSIA).

2. AIM OF THE PROGRAMMME

One of the APLAC's main aims is to build up and maintain mutual confidence in the technical competence of APLAC members. Interlaboratory comparisons provide objective evidence that laboratories are competent and that they can achieve the level of accuracy for which they are accredited. They also provide means for improving the quality and performance of laboratories throughout the region.

APLAC M025 pressure measurement programme was designed to test the participant's ability to perform calibration of pressure using a pressure calibrator over a specified range and to obtain values within their accredited uncertainties of measurement.

3. DESIGN OF THE PROGRAMME

This interlaboratory comparison involved the circulation of three pressure calibrators in three (3) loops of participating laboratories, designated as Loop A , Loop B and Loop C. The artefacts were identified as Artefact A, Artefact B and Artefact C and were circulated to Loop A, Loop B and Loop C respectively.

National Metrology Laboratory of SIRIM Berhad (NML-SIRIM), Malaysia acted as the Reference Laboratory, deriving values from a series of calibrations of the measurement artefacts at specific intervals within each calibration loop.

The instruments selected for use as artefacts need to have sufficient resolution, repeatability and stability.

Participants were required to carry out calibration from 10 MPa to 70 MPa at nominal temperature of 23 °C. Participants were allowed to use their own measurement methods. A copy of the '*Instructions to Laboratories and Result Sheets*' appears as in Appendix I.

4. PARTICIPANTS

Thirty six (36) laboratories were nominated for participation by nineteen (19) accreditation bodies. During the course of the programme, one (1) laboratory withdrew their participation, two (2) laboratories were not able to perform the measurement due to the malfunction of the artefact upon receipt and three (3) laboratories did not submit their results.

To maintain confidentiality, participating laboratories were assigned random Lab Code numbers and these numbers are used in this report.

5. CIRCULATION SCHEDULE

In order to keep to the schedule, all the accreditation bodies were asked to strictly follow the circulation period given to all laboratories before the starting of the programme. A circulation schedule of the artefacts to the accreditation bodies in each loop appears as in Table I, Table II and Table III of Appendix II. There were delays encountered in the circulation of the artefacts mainly due to customs clearance procedures in some countries.

6. REPORTING BY PARTICIPANTS

Laboratories were requested to report their test results on a pro-forma Results Sheet (refer to Appendix I of 'Instructions to Laboratories and Result Sheets'). The participating laboratories shall report the calibration uncertainties at 95% confidence level.

7. REFERENCE VALUES AND STABILITY OF THE ARTEFACTS

7.1 Assignment of Reference Values

The reference values obtained from the calibration artefacts are in terms of the deviations of the artefact readings from the standard pressure values applied at the specified measurement points. The reference value assigned for each laboratory in any particular circulation loop is the average of the readings measured by the Reference Laboratory at specific intervals within each circulation loop. Each loop has been assigned a different final reference value with its associated measurement uncertainty.

For Loop A and Loop B, the final reference value ($\overline{D}_{L,P,M}$) at each measurement point (P) for a particular mode (M - increasing / decreasing) has been calculated based on results obtained from measurements made at the beginning (b), middle (m) and end (e) of the loop by using the formula as follows:

$$\overline{D}_{L,P,M} = (\overline{D}_{L,P,M,b} + \overline{D}_{L,P,M,m} + \overline{D}_{L,P,M,e})/3 \quad \text{.......................................Eq. 1}$$

where $\overline{D}_{L,P,M,b}$ is the reference value calculated at the beginning of the loop based on the average of 3 readings. The second and third terms within the brackets in Eq. 1 refer to the reference values calculated in the similar manner at the middle and end of the same loop.

The notations used in Eq. 1 refer to the following items:
$\overline{D}$ = Reference value,
L = Loop identification (A, B),
P = Measurement point (nominal pressure value in MPa),
M = Mode of measurement (increasing or decreasing pressure),

It is to be reported that artefact C was measured by a first group of laboratories in USA and returned to the Reference Laboratory for a recalibration. It was then circulated to the next group of laboratories in Vietnam and India, following the voluntary withdrawal of the participation of the laboratory from ema, Mexico. However, the artefact C was found to have seriously malfunctioned when it was returned to the Reference Laboratory. As a result, no results were received from the laboratories in this group. The artefact was sent back to the manufacturer for repair. After the repair, the artefact was recalibrated before being circulated to the next group of laboratories in Malaysia. Please see Table III of Appendix II – Circulation Schedule for Loop C.

The first and final groups of laboratories in Loop C are identified as group C1 and group C2 respectively. Different final reference values (i.e. Ref C1 and Ref C2) are assigned to these two groups. Each of the final reference values has been calculated using Eq. 1, but based on results obtained from measurements made at the beginning and end of the particular circulation loop only (i.e. two measurements instead of three).

7.2 *Stability of Artefacts*

The calibrations performed by the Reference Laboratory at the specific intervals within each circulation loop showed that all the artefacts were reasonably stable with an error of less than 0.001 MPa. The drift effect (instability) has been included in the evaluation of uncertainty of the reference values.

8. INTERIM REPORTS

Upon receiving the calibration reports from the participating laboratories and completion of measurement of the reference value, interim reports were issued to the participating laboratories.

9. FINAL REFERENCE VALUES AND UNCERTAINTIES

The initial reference values as presented in the interim reports to the participating laboratories have been recalculated at the completion of the programme. Participating laboratories will notice there have been some changes to the reference values of the artefacts as reported in this final report. The change in reference values is attributed to some mistakes in assigning the value of the absolute 'g' and measured temperature of the reference standard in the earlier calculation.

The uncertainty of the reference values were reviewed and improved based on the uncertainty component contributions from the reference standard used, the individual characteristics of the artefacts and other relevant inputs.

The final reference values and their associated expanded measurement uncertainties are as shown in Appendix III.

10. SUMMARY OF RESULTS

In accordance with the international practice, measurement performance has been assessed on the basis of an E_n ratio for each measurement. The E_n ratios are calculated using a standard statistical technique for comparing values and are derived from the following expression:

$$E_n = \frac{LAB - REF}{\sqrt{{U_{LAB}}^2 + {U_{REF}}^2}}$$

where:

LAB	is the pressure deviation of the indication of the artefact at nominal value measured by the participating laboratory.
REF	is the final reference value as determined from measured pressure deviations made at specific intervals within each circulation loop by the Reference Laboratory using Eq. 1.
U_{LAB}	is the expanded uncertainty of the pressure deviation provided by the participating laboratory.
U_{REF}	is the expanded uncertainty of the pressure deviation evaluated by the Reference Laboratory.

For the results to be acceptable, values of $|E_n| \leq 1.0$ are required. Values of $|E_n| > 1.0$ require investigation and corrective action by the laboratory concerned.

The deviation of the each laboratory's result from the reference value, i.e. (*LAB* – *REF*) is summarised as in Table 1.

Table 2 summarises the measurement uncertainties reported by the laboratories at 95% confidence level and coverage factor of $k = 2$.

Table 3 gives a summary of the calculated $|E_n|$ values.

The graphs in Figures 1 to 6 plot the values of (*LAB* – *REF*) and associated uncertainties of the laboratories.

Table 1- Summary of *LAB - REF* (MPa)

Lab Code / Nominal Pressure (MPa)	REF	A01	A04	A05	A10	A11	A12	A13	A14	A15	A29	A30	A31	A32	B06	B07
10	0.000	-0.001	0.000	0.000	-0.002	0.000	-0.005	0.000	-0.002	0.005	-0.009	-0.003	-0.001	0.000	0.002	-0.007
20	0.000	0.040	0.001	0.000	-0.002	0.001	-0.006	0.001	0.001	0.009	-0.011	-0.004	0.002	0.003	0.001	-0.007
30	0.000	0.000	0.001	0.000	-0.005	0.001	-0.008	0.001	0.003	0.010	-0.015	-0.006	0.003	0.002	0.000	-0.008
40	0.000	0.000	0.001	0.000	-0.005	0.000	-0.010	0.000	0.005	0.010	-0.019	-0.009	0.004	0.003	0.001	-0.006
50	0.000	-0.001	0.001	0.008	-0.008	0.002	-0.012	0.001	0.006	0.007	-0.022	-0.013	0.004	0.002	0.000	-0.007
60	0.000	0.000	0.002	0.008	-0.013	0.002	-0.014	0.002	0.007	0.008	-0.025	-0.015	0.001	0.005	0.000	-0.007
70	0.000	0.001	0.002	0.006	-0.016	-0.001	-0.015	0.001	0.008	0.006	-0.030	-0.017	0.001	0.006	-0.001	-0.008
70	0.000	0.001	0.002	0.006	-0.016	-0.001	-0.017	0.000	0.008	0.006	-0.030	-0.017	0.001	0.006	-0.001	-0.006
60	0.000	-0.002	0.001	0.006	-0.012	0.002	-0.015	0.001	0.006	0.007	-0.026	-0.015	0.001	0.004	0.000	-0.007
50	0.000	-0.003	-0.001	0.003	-0.011	0.000	-0.014	-0.002	0.005	0.005	-0.025	-0.014	0.001	0.001	-0.001	-0.008
40	0.000	-0.003	-0.001	0.000	-0.005	-0.001	-0.012	-0.003	0.002	0.007	-0.022	-0.011	0.002	0.001	0.000	-0.009
30	0.000	-0.002	0.000	0.000	-0.005	0.000	-0.009	-0.001	0.002	0.008	-0.016	-0.007	0.003	0.001	0.000	-0.009
20	0.000	-0.003	-0.001	-0.001	-0.003	0.000	-0.006	-0.001	-0.001	0.006	-0.014	-0.006	0.001	0.001	-0.001	-0.010
10	0.000	-0.022	-0.001	-0.001	-0.004	-0.001	-0.004	-0.002	-0.004	0.004	-0.010	-0.004	-0.001	-0.001	0.001	-0.009

Table 1- Summary of *LAB-REF* (MPa)*(continued)*

Lab Code / Nominal Pressure (MPa)	B08	B09	B21	B22	B23	B25	B26	C02	C03	C27	C28	C33	C34	C35	C36
10	-0.001	0.001	0.001	-0.001	0.001	0.003	0.001	-0.013	0.000	0.049	-0.004	-0.001	0.002	-0.028	-0.003
20	-0.002	0.002	0.001	-0.001	0.001	0.003	-0.001	-0.010	0.000	0.098	-0.009	0.000	0.004	-0.054	-0.001
30	-0.003	0.001	0.000	-0.002	0.001	0.003	-0.003	-0.008	0.000	0.145	-0.006	0.001	0.004	-0.082	0.003
40	-0.004	0.002	0.001	-0.002	0.002	0.004	-0.003	-0.002	0.004	0.194	-0.007	-0.001	0.004	-0.112	0.002
50	-0.007	0.002	0.001	-0.002	0.000	0.003	-0.005	0.002	0.005	0.240	-0.007	0.001	0.005	-0.136	0.005
60	-0.010	0.002	0.000	-0.002		0.003	-0.006	0.007	0.008	0.284	-0.008	-0.002	-0.005	-0.167	0.000
70	-0.016	0.001	-0.001	-0.003		0.002	-0.009	0.014	0.009	0.334		-0.001	0.006	-0.195	0.001
70	-0.016	0.000	-0.002	-0.003		0.002	-0.008	0.013	0.010	0.334		-0.001	0.006	-0.195	0.001
60	-0.011	0.001	-0.001	-0.003		0.003	-0.006	0.006	0.004	0.286	-0.007	-0.001	-0.005	-0.167	0.000
50	-0.010	0.001	-0.001	-0.002	0.000	0.002	-0.006	0.002	0.005	0.244	-0.005	0.000	0.005	-0.137	0.005
40	-0.005	0.001	0.001	-0.002	0.000	0.002	-0.004	-0.003	0.003	0.196	-0.005	-0.002	0.004	-0.113	0.002
30	-0.002	0.001	0.001	-0.001	0.001	0.003	-0.002	-0.011	-0.002	0.145	-0.009	0.000	0.004	-0.085	0.003
20	-0.002	0.001	0.001	-0.001	-0.001	0.003	-0.001	-0.010	0.002	0.101	-0.008	0.000	0.004	-0.058	-0.001
10	-0.001	0.001	0.001	-0.001	-0.004	0.003	0.001	-0.013	0.001	0.052	-0.004	-0.002	0.002	-0.019	-0.003

Table 2 – Summary of Uncertainties (MPa)

Lab Code / Nominal Pressure (MPa)	REF A	REF B	REF C1	REF C2	A01	A04	A05	A10	A11	A12	A13	A14	A15	A29	A30	A31	A32
10	0.0017	0.0017	0.0017	0.0017	0.0011	0.0013	0.112	0.02	0.0032	0.0024	0.0019	0.0043	0.0014	0.004	0.0113	0.003	0.002
20	0.0018	0.0018	0.0018	0.0018	0.0021	0.0015	0.112	0.02	0.0063	0.0038	0.0023	0.0074	0.0020	0.008	0.0125	0.003	0.003
30	0.0019	0.0019	0.0019	0.0019	0.0032	0.0017	0.112	0.02	0.0093	0.0054	0.0029	0.0108	0.0027	0.012	0.0142	0.003	0.005
40	0.0021	0.0021	0.0021	0.0021	0.0043	0.0020	0.112	0.02	0.0124	0.0071	0.0036	0.0142	0.0035	0.016	0.0164	0.004	0.006
50	0.0023	0.0023	0.0023	0.0023	0.0053	0.0023	0.112	0.02	0.0155	0.0088	0.0043	0.0178	0.0040	0.020	0.0188	0.005	0.008
60	0.0026	0.0026	0.0026	0.0026	0.0064	0.0027	0.112	0.02	0.0185	0.0105	0.0050	0.0215	0.0049	0.024	0.0213	0.005	0.009
70	0.0029	0.0028	0.0028	0.0029	0.0074	0.0031	0.112	0.02	0.0216	0.0122	0.0058	0.0253	0.0058	0.028	0.0240	0.006	0.011
70	0.0029	0.0028	0.0028	0.0029	0.0074	0.0031	0.112	0.02	0.0216	0.0122	0.0058	0.0253	0.0058	0.028	0.0240	0.006	0.011
60	0.0026	0.0026	0.0026	0.0026	0.0064	0.0027	0.112	0.02	0.0186	0.0105	0.0050	0.0216	0.0049	0.024	0.0213	0.005	0.009
50	0.0023	0.0023	0.0023	0.0023	0.0053	0.0023	0.112	0.02	0.0155	0.0088	0.0043	0.0184	0.0040	0.020	0.0188	0.005	0.008
40	0.0021	0.0021	0.0021	0.0021	0.0043	0.0020	0.112	0.02	0.0124	0.0071	0.0036	0.0143	0.0035	0.016	0.0164	0.004	0.006
30	0.0019	0.0019	0.0019	0.0019	0.0032	0.0017	0.112	0.02	0.0093	0.0054	0.0029	0.0108	0.0027	0.012	0.0142	0.003	0.005
20	0.0018	0.0018	0.0018	0.0018	0.0021	0.0015	0.112	0.02	0.0062	0.0038	0.0023	0.0075	0.0020	0.008	0.0125	0.003	0.003
10	0.0017	0.0017	0.0017	0.0017	0.0011	0.0013	0.112	0.02	0.0032	0.0024	0.0019	0.0043	0.0014	0.004	0.0113	0.002	0.002

Table 2 – Summary of Uncertainties (MPa)*(continued)*

Lab Code / Nominal Pressure (MPa)	B06	B07	B08	B09	B21	B22	B23	B25	B26	C02	C03	C27	C28	C33	C34	C35	C36
10	0.0020	0.012	0.002	0.020	0.0007	0.0010	0.00140	0.0098	0.0016	0.0001	0.0008	0.0016	0.005	0.003	0.023	0.003	0.007
20	0.0034	0.012	0.002	0.020	0.0012	0.0012	0.00194	0.0099	0.0032	0.0024	0.0017	0.0012	0.010	0.004	0.023	0.006	0.007
30	0.0034	0.012	0.003	0.020	0.0015	0.0014	0.00261	0.0100	0.0048	0.0031	0.0025	0.0020	0.015	0.005	0.023	0.009	0.007
40	0.0034	0.012	0.005	0.020	0.0016	0.0020	0.00345	0.0100	0.0064	0.0030	0.0033	0.0031	0.020	0.007	0.023	0.012	0.020
50	0.0049	0.012	0.005	0.020	0.0020	0.0022	0.00411	0.0100	0.0080	0.0037	0.0042	0.0032	0.025	0.008	0.023	0.015	0.020
60	0.0049	0.012	0.007	0.020	0.0024	0.0026		0.0100	0.0096	0.0044	0.0050	0.0035	0.030	0.009	0.023	0.018	0.020
70	0.0049	0.012	0.008	0.020	0.0028	0.0028		0.0110	0.0112	0.0050	0.0059	0.0053		0.011	0.023	0.021	0.020
70	0.0049	0.012	0.008	0.020	0.0034	0.0028		0.0110	0.0112	0.0053	0.0059	0.0053		0.011	0.023	0.021	0.020
60	0.0049	0.012	0.007	0.020	0.0027	0.0026		0.0100	0.0096	0.0047	0.0050	0.0035	0.030	0.009	0.023	0.018	0.020
50	0.0049	0.012	0.005	0.020	0.0029	0.0022	0.00432	0.0100	0.0080	0.0040	0.0042	0.0040	0.025	0.008	0.023	0.015	0.020
40	0.0034	0.012	0.004	0.020	0.0021	0.0020	0.00330	0.0100	0.0064	0.0034	0.0033	0.0039	0.020	0.007	0.023	0.012	0.020
30	0.0034	0.012	0.003	0.020	0.0019	0.0014	0.00254	0.0100	0.0048	0.0024	0.0025	0.0031	0.015	0.005	0.023	0.009	0.007
20	0.0034	0.012	0.002	0.020	0.0023	0.0012	0.00194	0.0099	0.0032	0.0018	0.0017	0.0040	0.010	0.004	0.023	0.006	0.007
10	0.0020	0.012	0.002	0.020	0.0022	0.0010	0.00179	0.0098	0.0016	0.0021	0.0008	0.0052	0.005	0.003	0.023	0.003	0.007

Table 3 – Summary of $|E_n|$ Values

Lab Code / Nominal Pressure (MPa)	A01	A04	A05	A10	A11	A12	A13	A14	A15	A29	A30	A31	A32	B06	B07	B08
10	0.5	0.0	0.0	0.1	0.1	1.8	0.1	0.4	2.4	2.0	0.3	0.3	0.0	0.7	0.6	0.3
20	14.2	0.4	0.0	0.1	0.1	1.4	0.5	0.2	3.3	1.4	0.3	0.6	0.8	0.3	0.6	0.9
30	0.1	0.3	0.0	0.3	0.1	1.4	0.2	0.3	3.0	1.2	0.5	0.9	0.3	0.1	0.6	0.9
40	0.1	0.3	0.0	0.2	0.0	1.3	0.1	0.3	2.4	1.2	0.6	0.9	0.6	0.2	0.5	0.7
50	0.1	0.4	0.1	0.4	0.1	1.3	0.2	0.3	1.5	1.1	0.7	0.6	0.3	0.1	0.6	1.3
60	0.0	0.5	0.1	0.6	0.1	1.3	0.3	0.3	1.4	1.0	0.7	0.2	0.5	0.0	0.6	1.4
70	0.1	0.4	0.0	0.8	0.0	1.2	0.1	0.3	0.9	1.1	0.7	0.2	0.5	0.2	0.7	1.8
70	0.1	0.4	0.0	0.8	0.0	1.3	0.0	0.3	0.9	1.1	0.7	0.2	0.5	0.2	0.5	1.8
60	0.3	0.2	0.1	0.6	0.1	1.4	0.2	0.3	1.3	1.1	0.7	0.2	0.4	0.1	0.6	1.5
50	0.6	0.4	0.0	0.5	0.0	1.6	0.3	0.3	1.0	1.3	0.7	0.2	0.1	0.2	0.7	1.8
40	0.7	0.4	0.0	0.3	0.1	1.7	0.6	0.1	1.6	1.3	0.7	0.5	0.1	0.1	0.7	1.0
30	0.6	0.2	0.0	0.3	0.0	1.5	0.4	0.2	2.5	1.3	0.5	0.7	0.2	0.1	0.7	0.7
20	1.0	0.3	0.0	0.1	0.1	1.5	0.5	0.1	2.4	1.7	0.5	0.2	0.3	0.2	0.8	0.7
10	10.9	0.5	0.0	0.2	0.4	1.3	0.7	0.8	2.0	2.2	0.4	0.5	0.3	0.3	0.8	0.2

Table 3 – Summary of $|E_n|$ Values *(continued)*

Lab Code / Nominal Pressure (MPa)	B09	B21	B22	B23	B25	B26	C02	C03	C27	C28	C33	C34	C35	C36
10	0.1	0.5	0.7	0.4	0.3	0.4	7.8	0.1	21.2	0.7	0.4	0.1	8.1	0.4
20	0.1	0.3	0.5	0.5	0.3	0.2	3.5	0.1	45.1	0.9	0.0	0.2	8.6	0.2
30	0.0	0.0	0.7	0.4	0.3	0.6	2.2	0.0	52.5	0.4	0.2	0.2	8.9	0.4
40	0.1	0.5	0.6	0.5	0.4	0.4	0.7	1.0	51.7	0.3	0.1	0.2	9.2	0.1
50	0.1	0.3	0.6	0.0	0.3	0.5	0.5	1.0	61.0	0.3	0.1	0.2	9.0	0.3
60	0.1	0.1	0.6		0.3	0.6	1.3	1.5	65.2	0.3	0.2	0.2	9.2	0.0
70	0.1	0.2	0.6		0.2	0.7	2.3	1.4	55.3		0.1	0.2	9.2	0.0
70	0.0	0.3	0.7		0.2	0.7	2.1	1.6	55.3		0.1	0.2	9.2	0.0
60	0.1	0.2	0.8		0.3	0.6	1.1	0.8	65.7	0.2	0.1	0.2	9.2	0.0
50	0.1	0.3	0.7	0.0	0.2	0.7	0.5	1.1	52.8	0.2	0.0	0.2	9.1	0.3
40	0.0	0.2	0.8	0.1	0.2	0.6	0.8	0.8	44.3	0.2	0.2	0.2	9.3	0.1
30	0.1	0.2	0.4	0.2	0.3	0.4	3.5	0.5	40.0	0.6	0.1	0.2	9.3	0.4
20	0.1	0.5	0.6	0.2	0.3	0.3	3.9	0.7	22.9	0.8	0.0	0.2	9.2	0.2
10	0.0	0.5	0.5	1.5	0.3	0.6	5.0	0.3	9.4	0.8	0.6	0.1	5.4	0.4

Figures 1(a to g): *LAB-REF* at Increasing Mode for Loop A

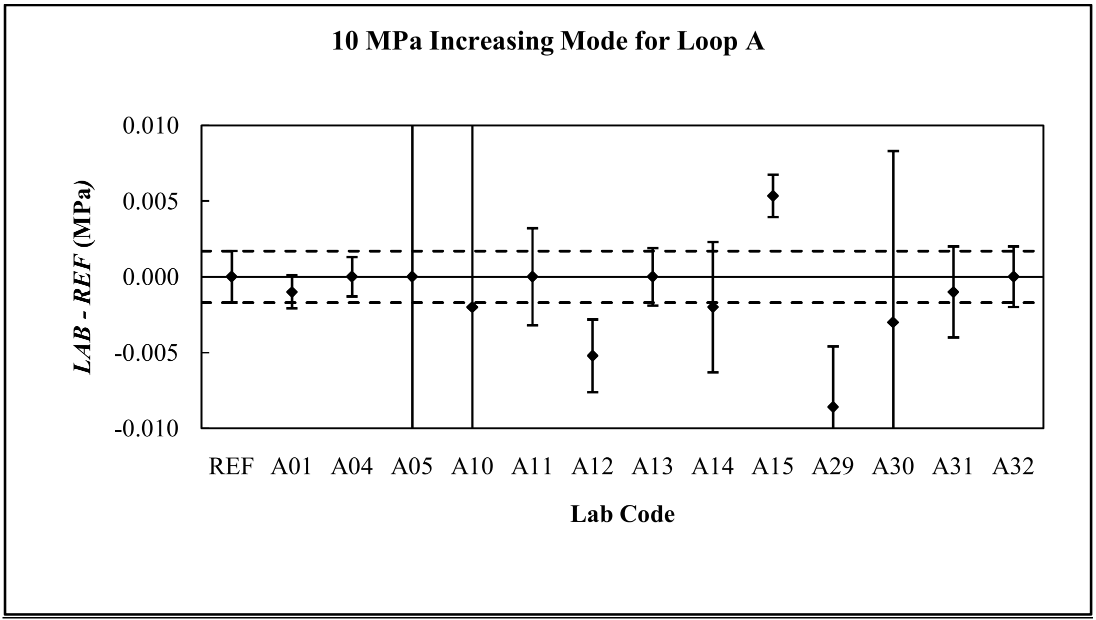


Figure 1a

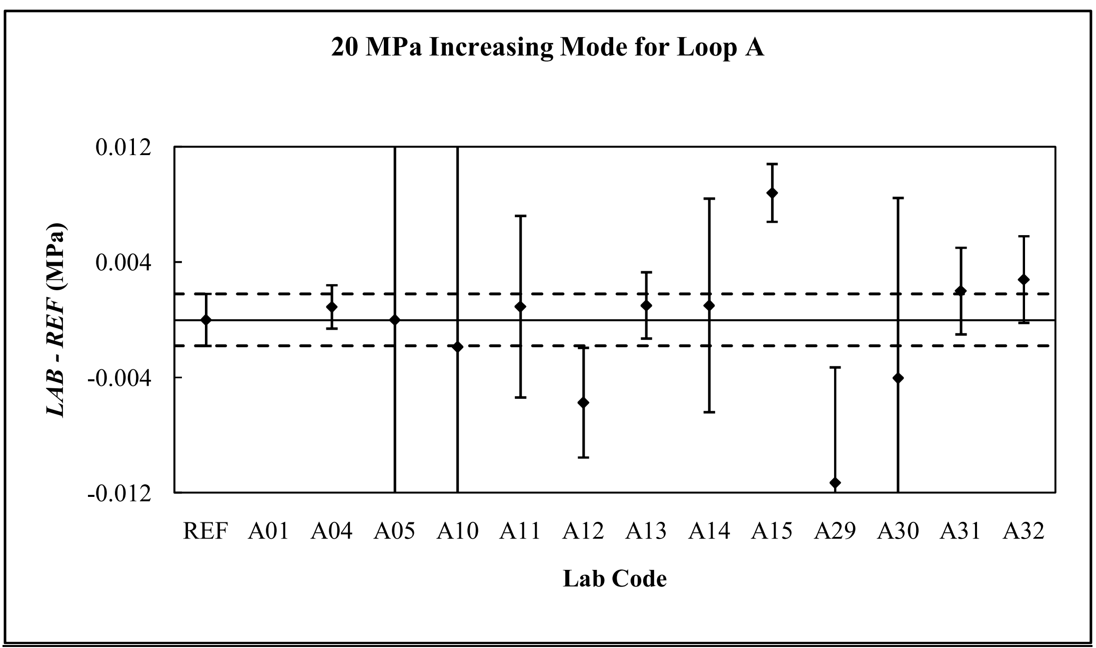


Figure 1b

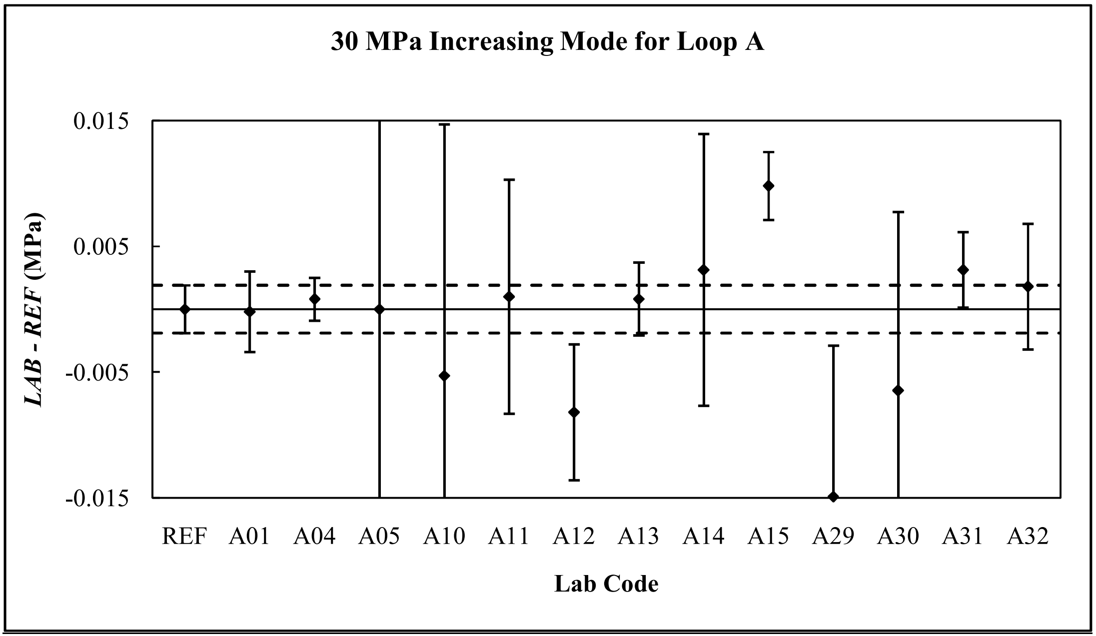


Figure 1c

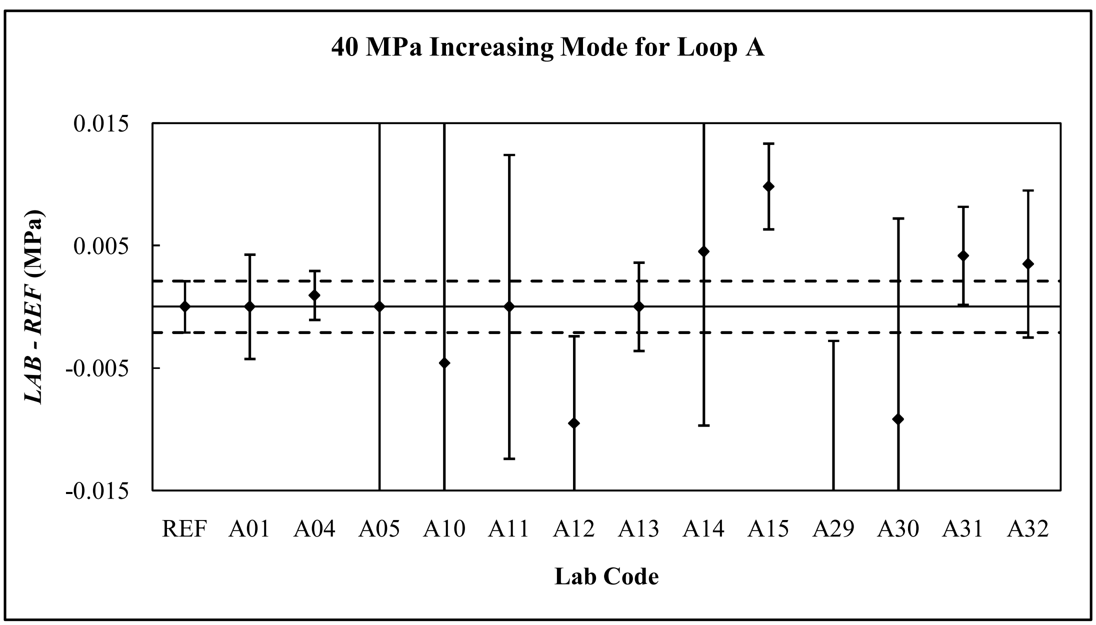


Figure 1d

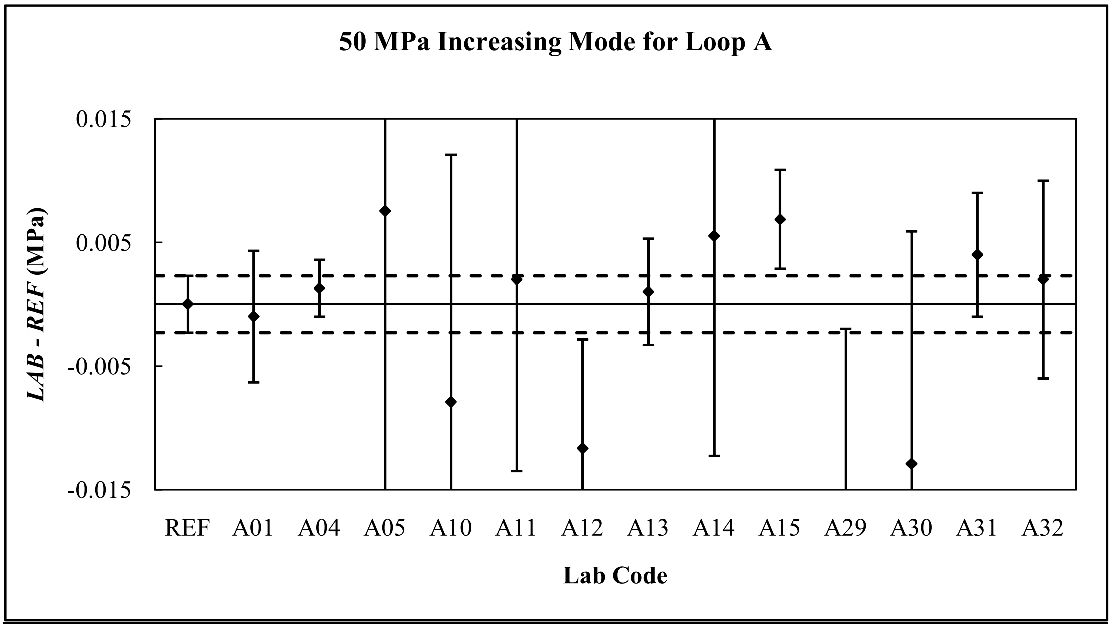


Figure 1e

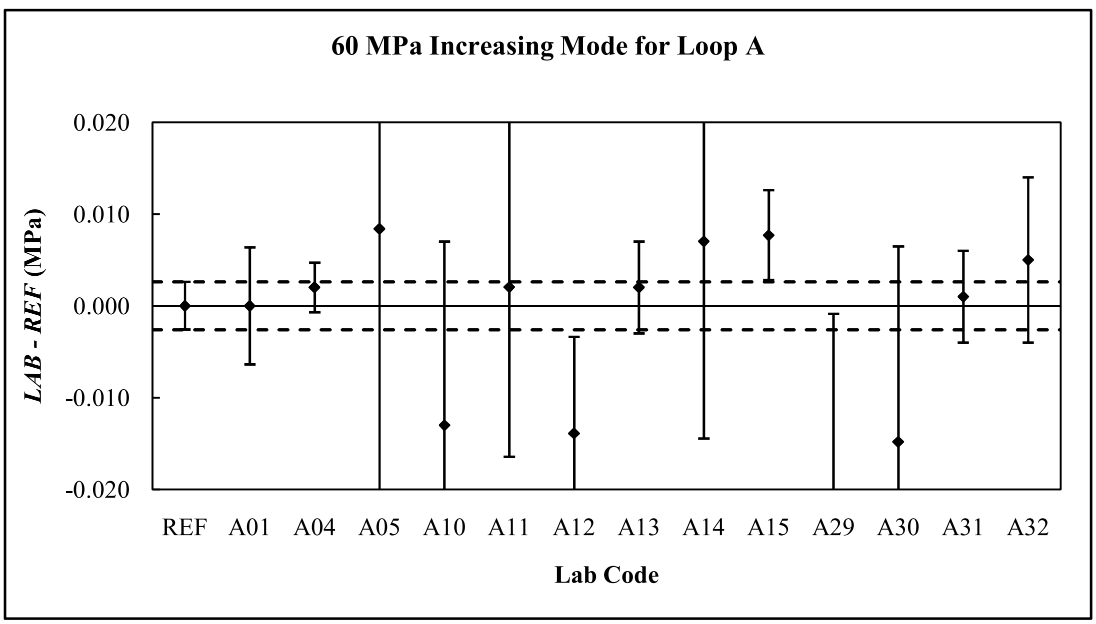


Figure 1f

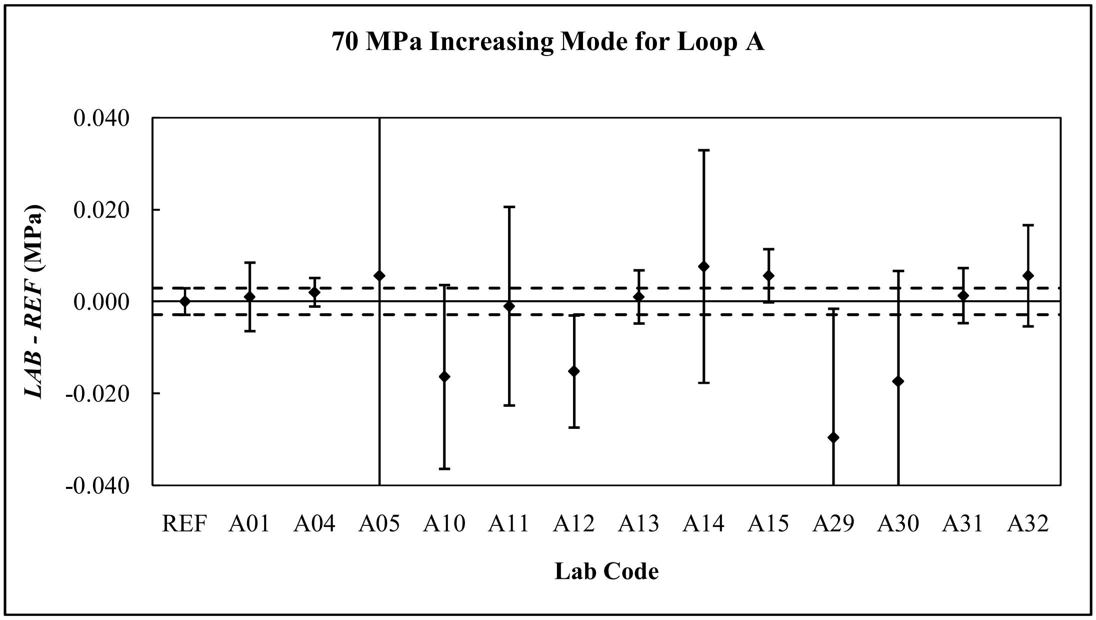


Figure 1g

Figures 2(a to g): *LAB-REF* at Increasing Mode for Loop B

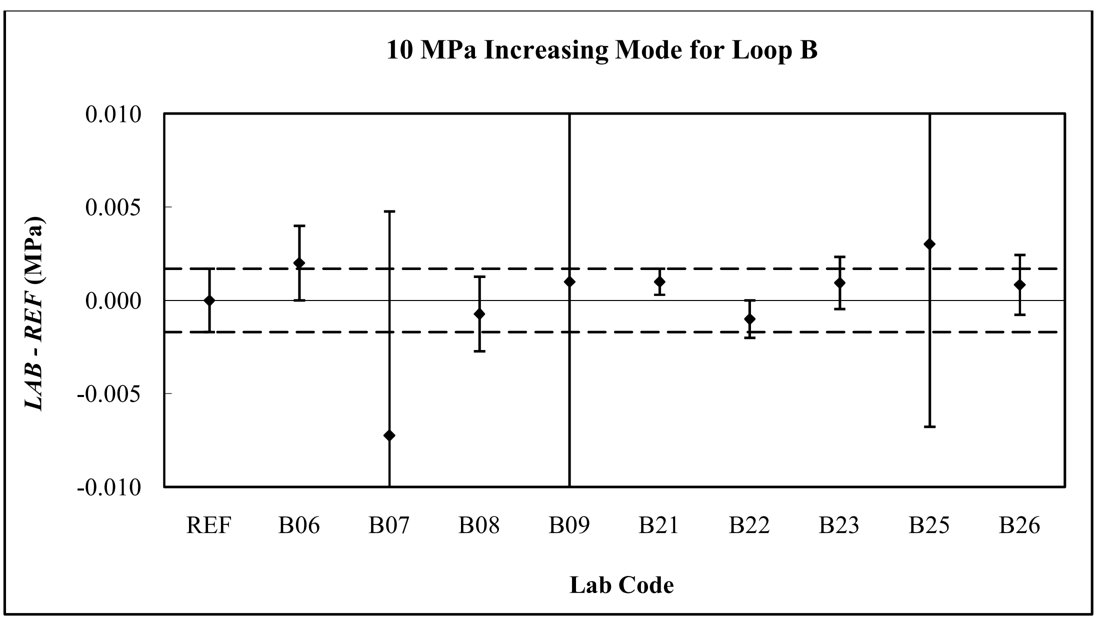


Figure 2a

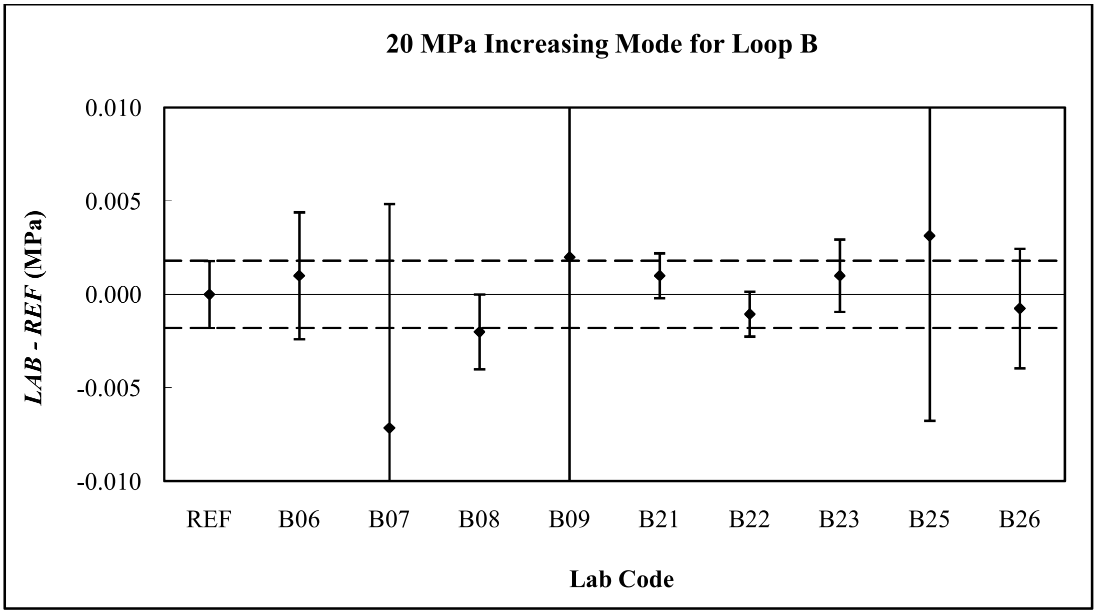


Figure 2b

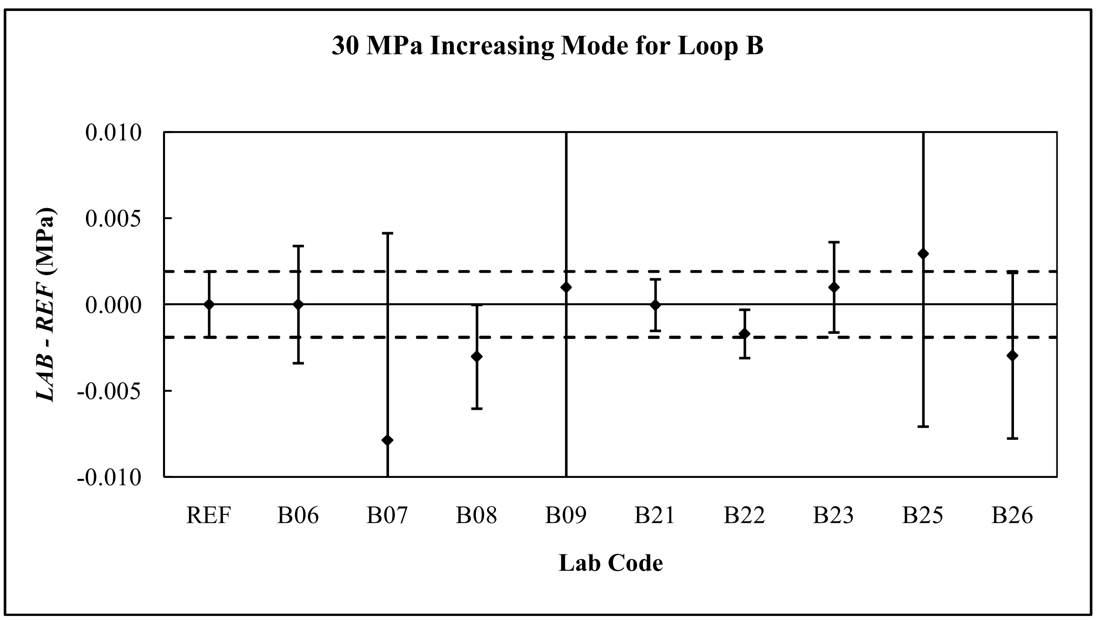
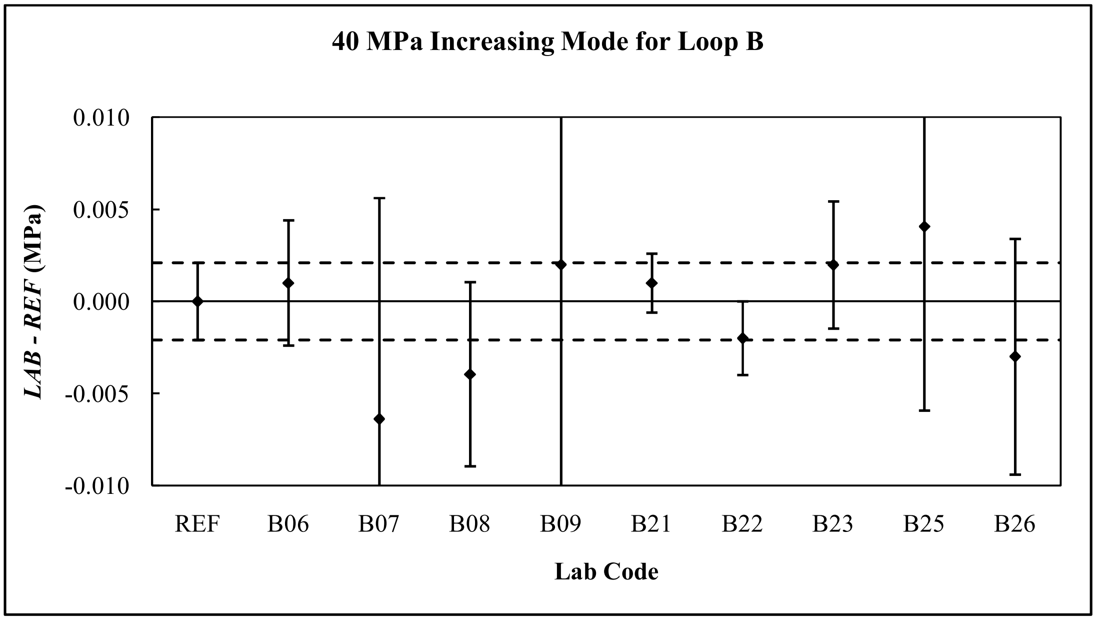


Figure 2c



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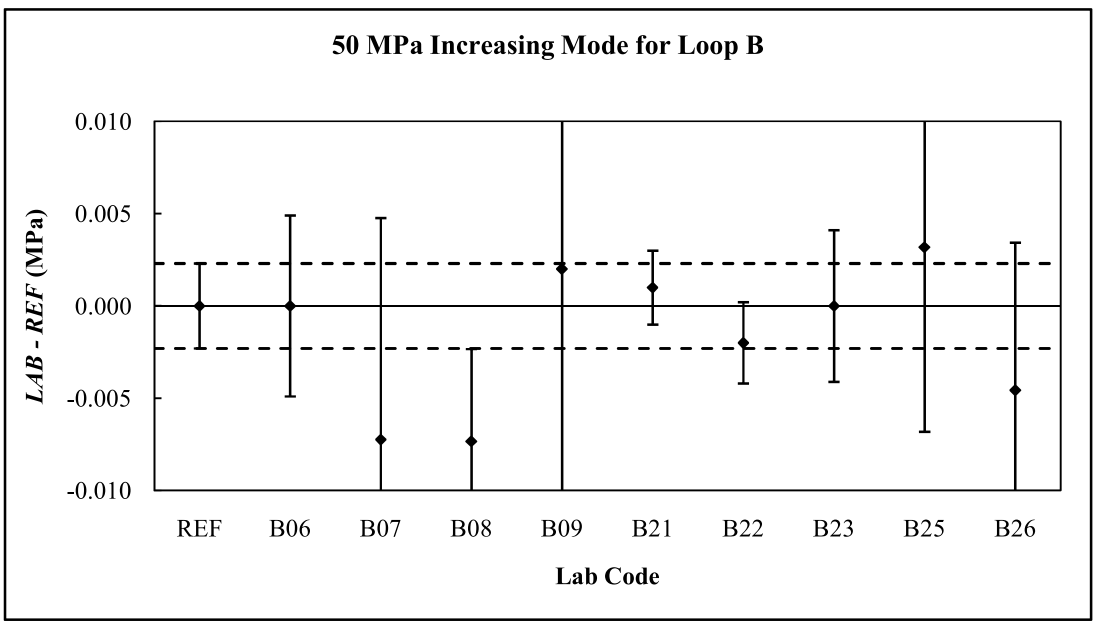


Figure 2e

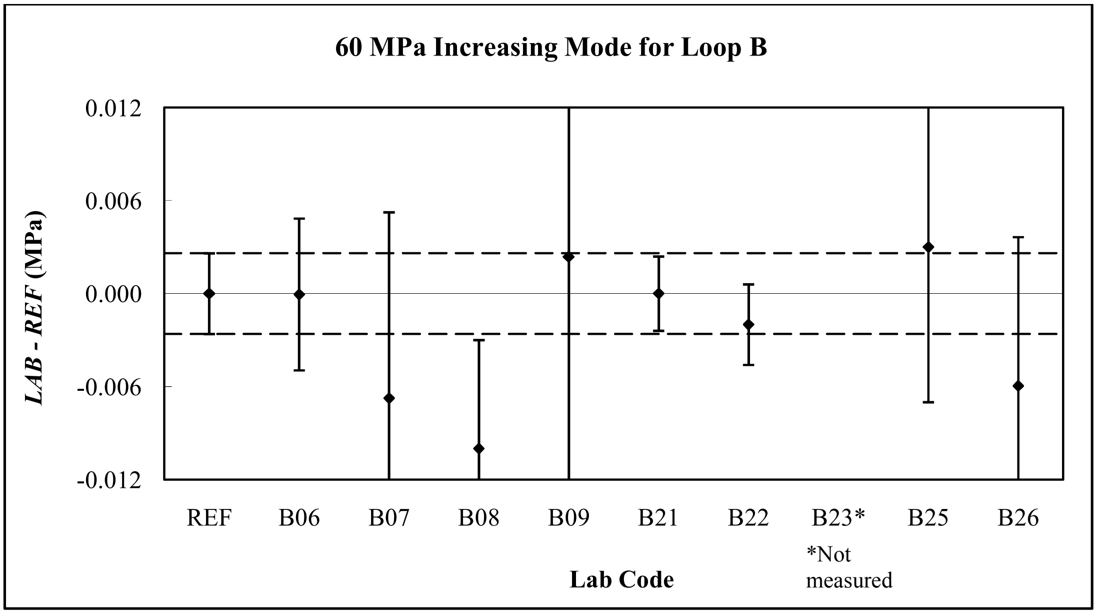


Figure 2f

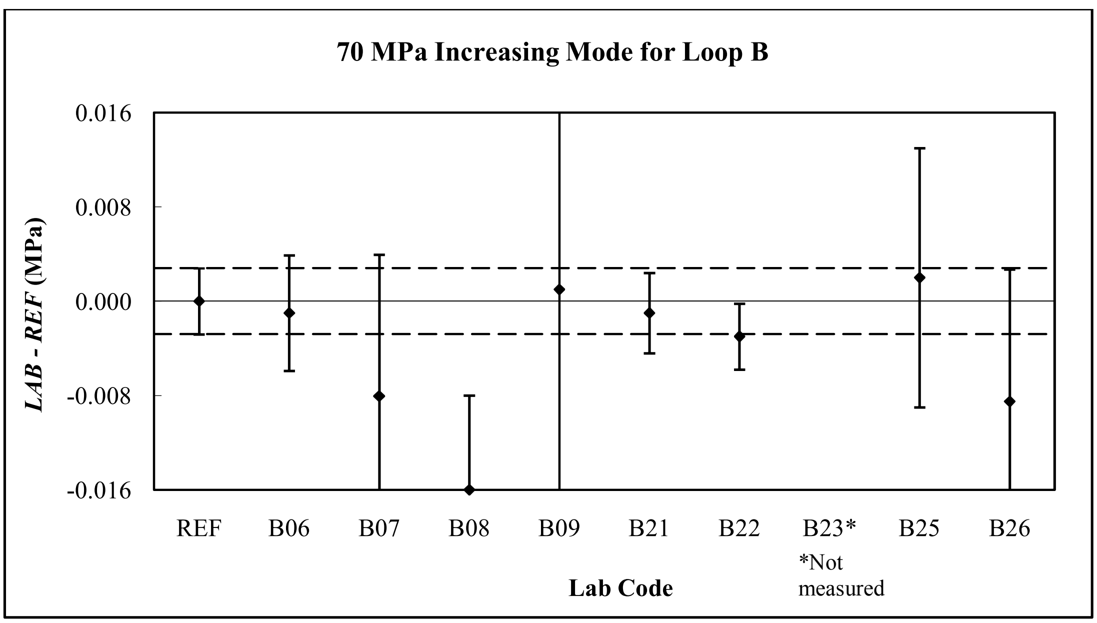


Figure 2g

Figures 3(a to n): *LAB-REF* at Increasing Mode for Loop C

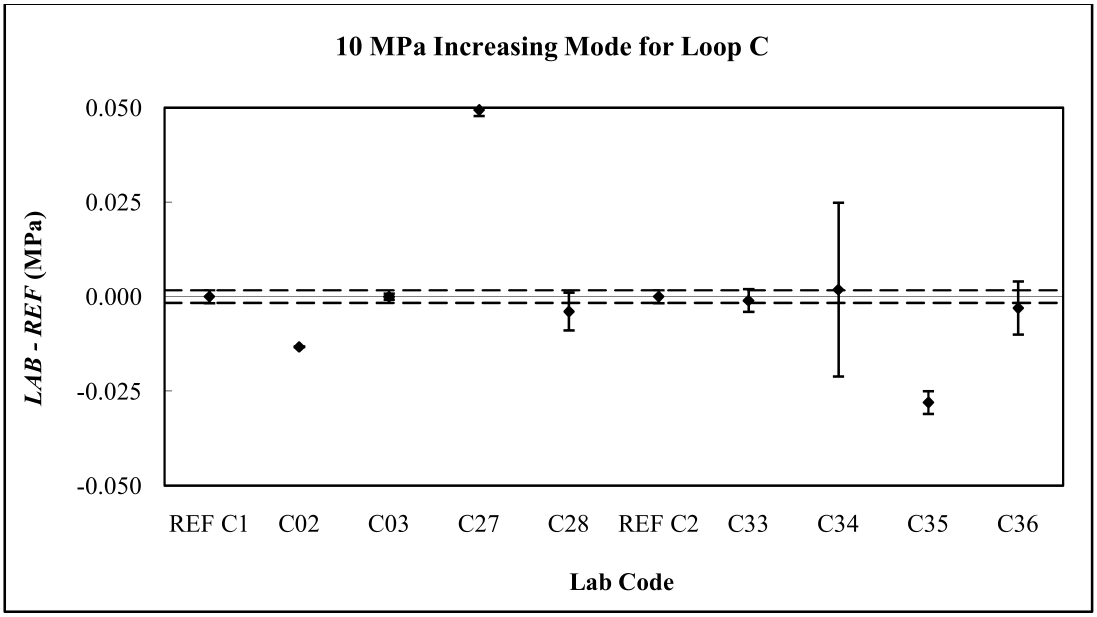


Figure 3a

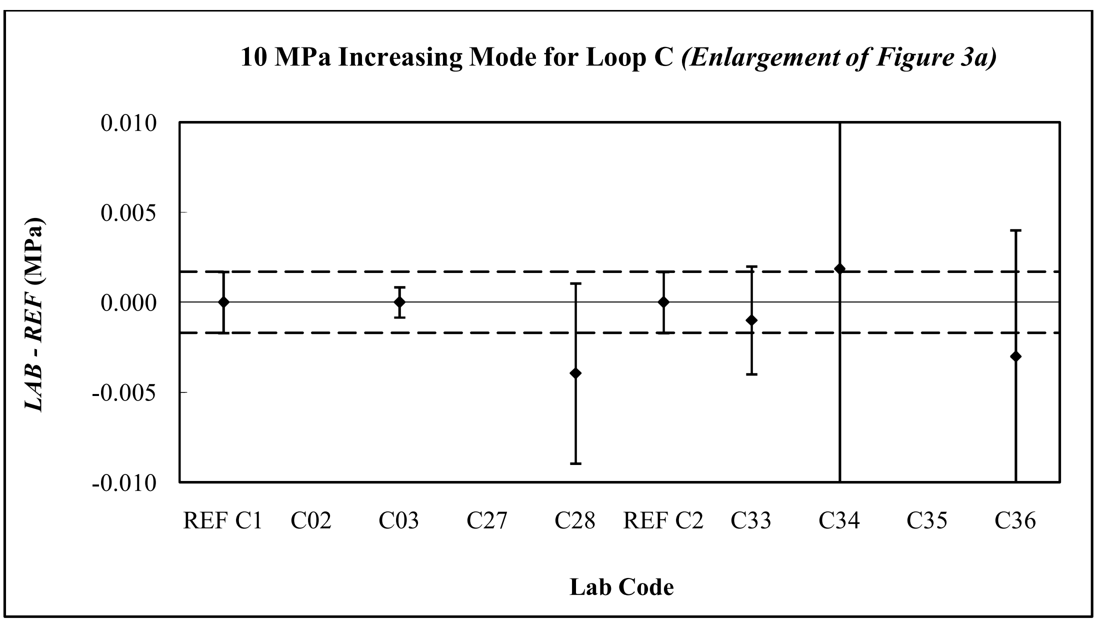


Figure 3b

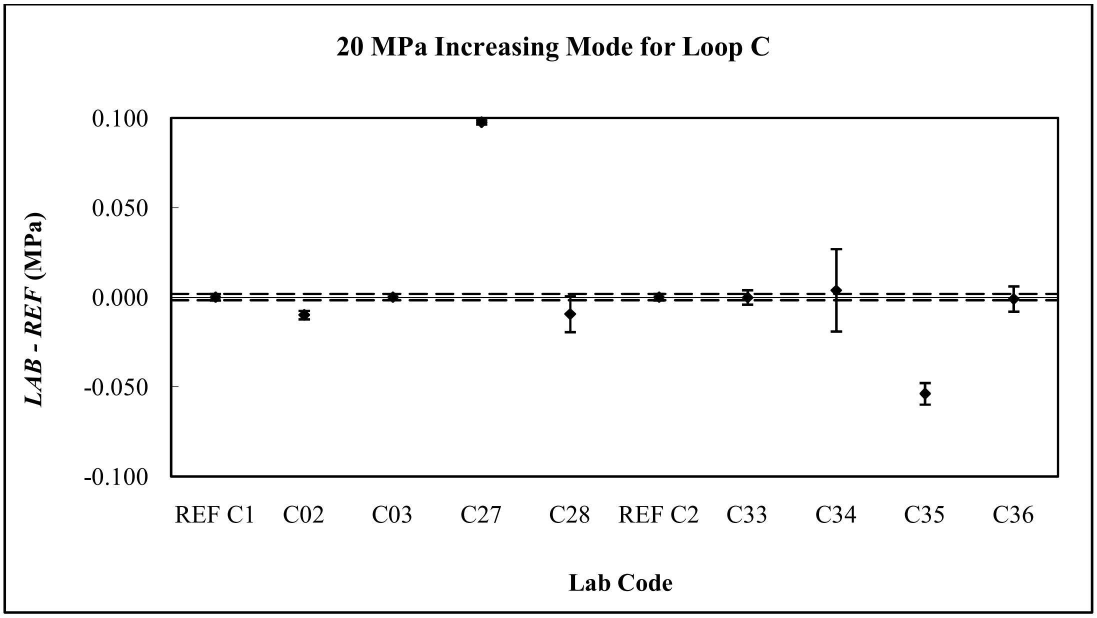


Figure 3c

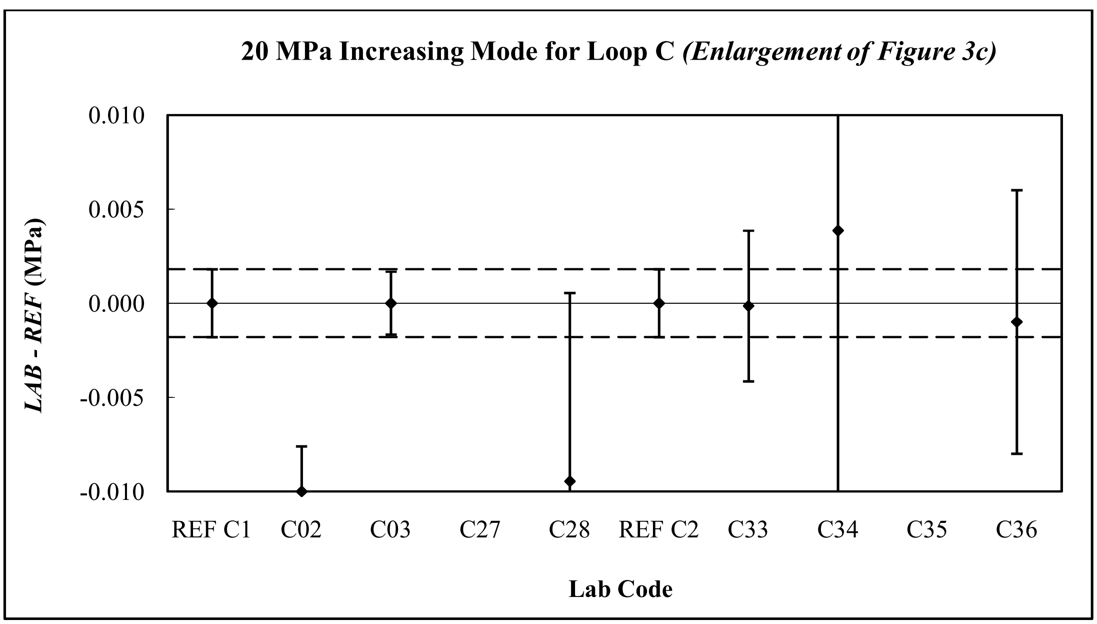


Figure 3d

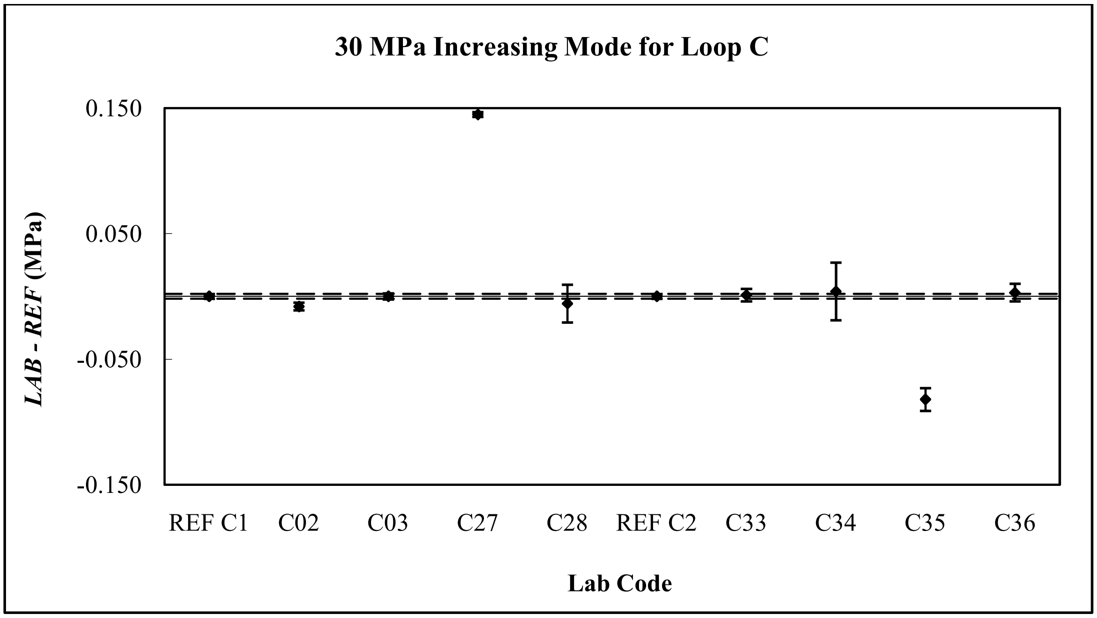


Figure 3e

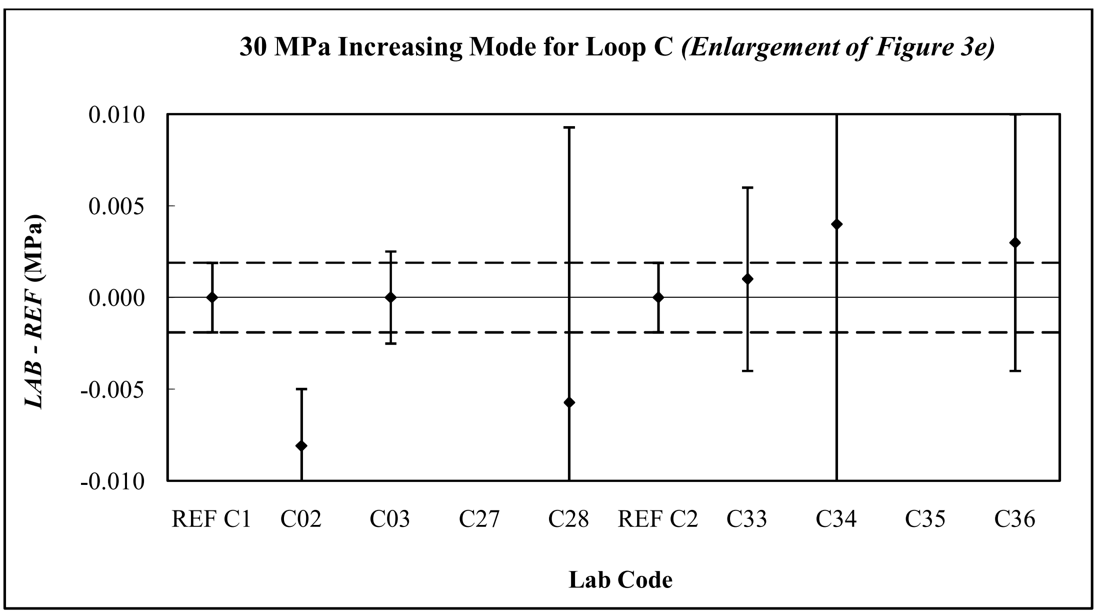


Figure 3f

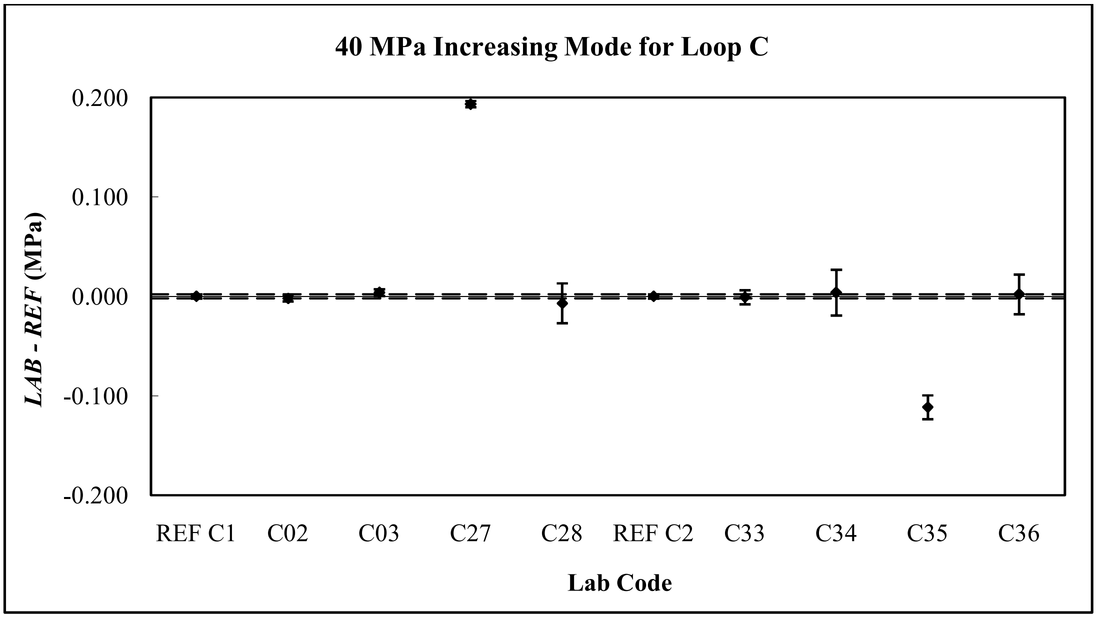


Figure 3g

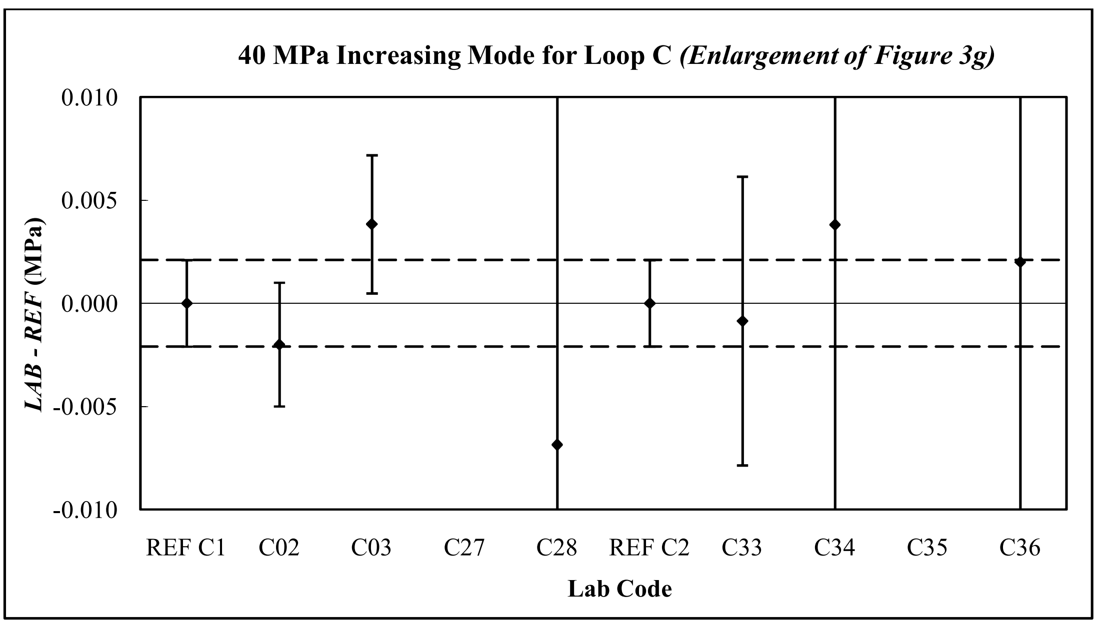


Figure 3h

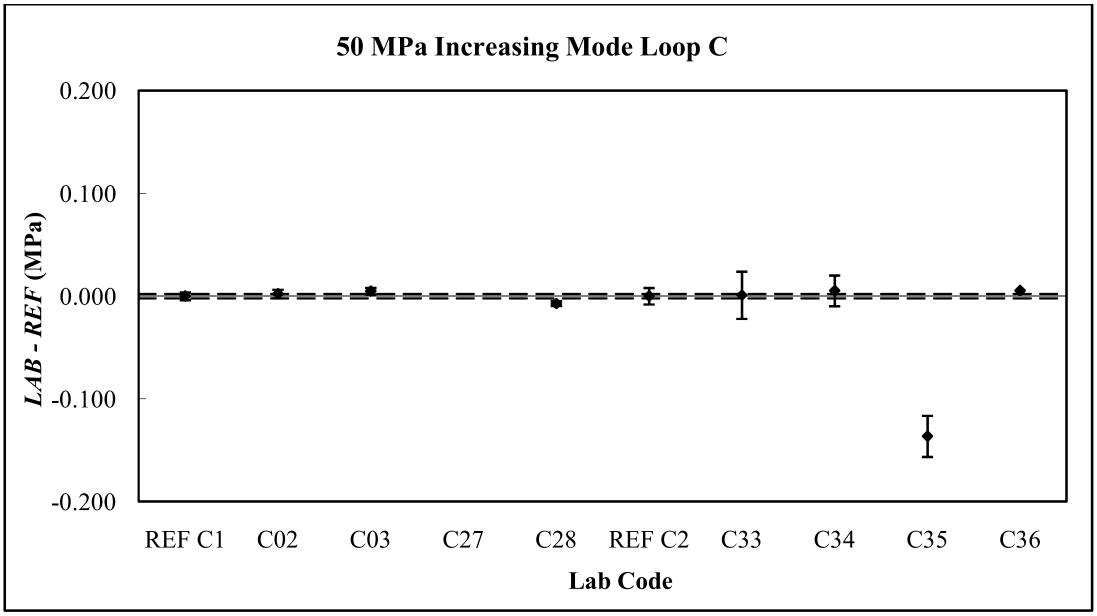


Figure 3i

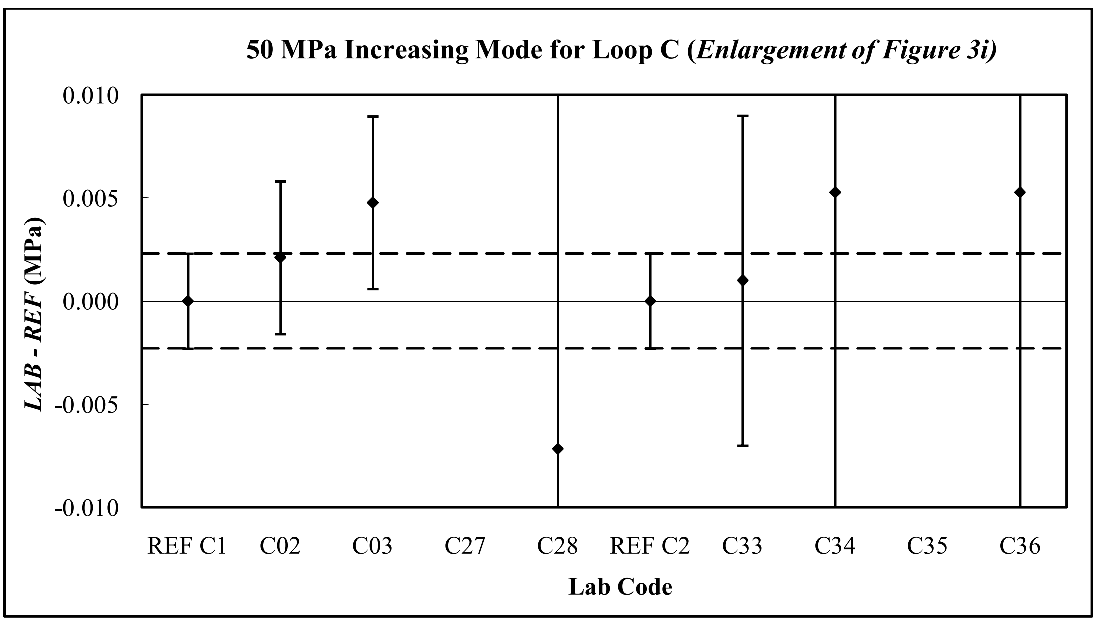


Figure 3j

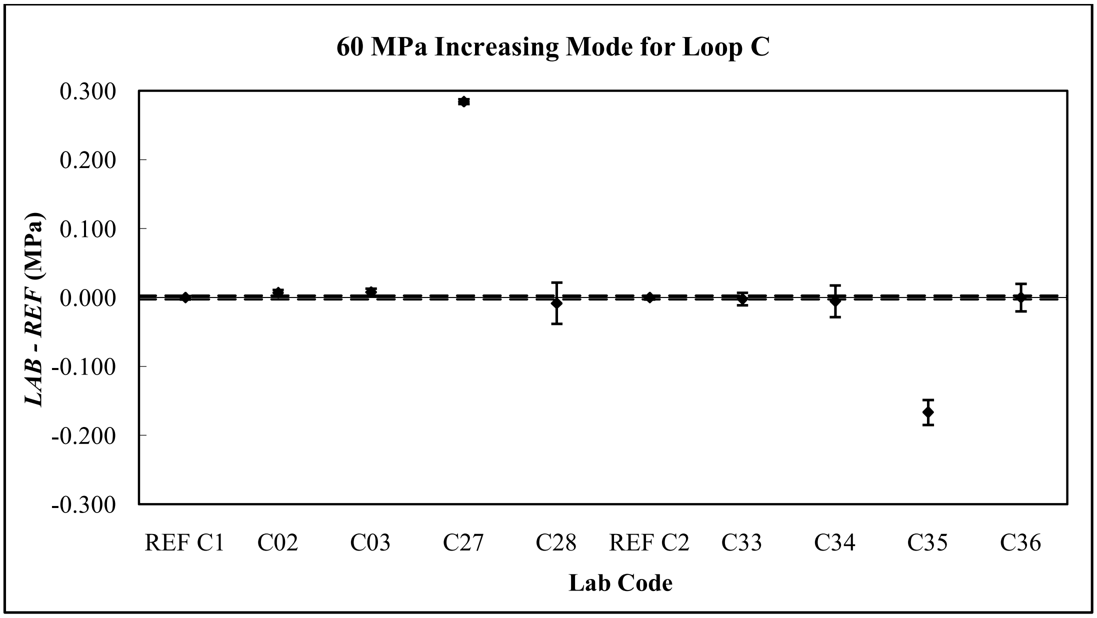


Figure 3k

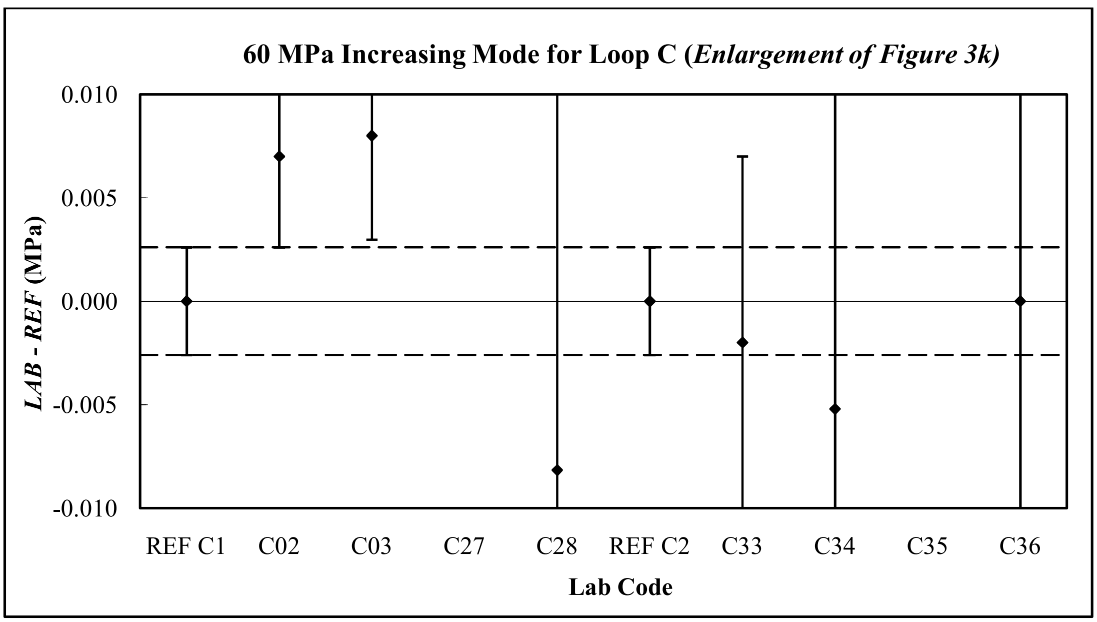


Figure3l

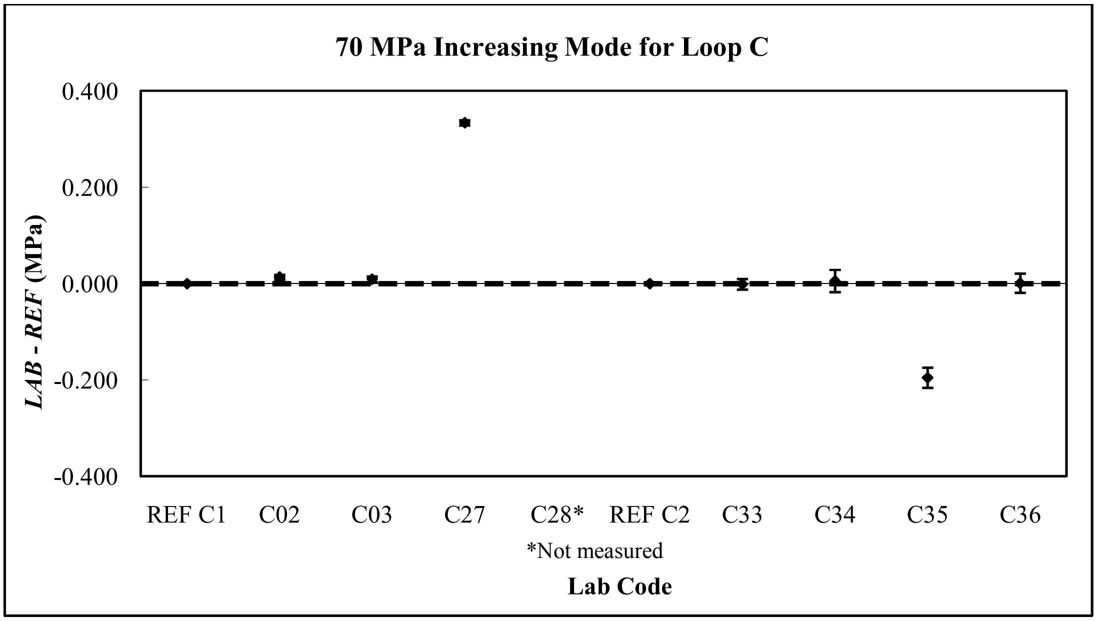


Figure 3m

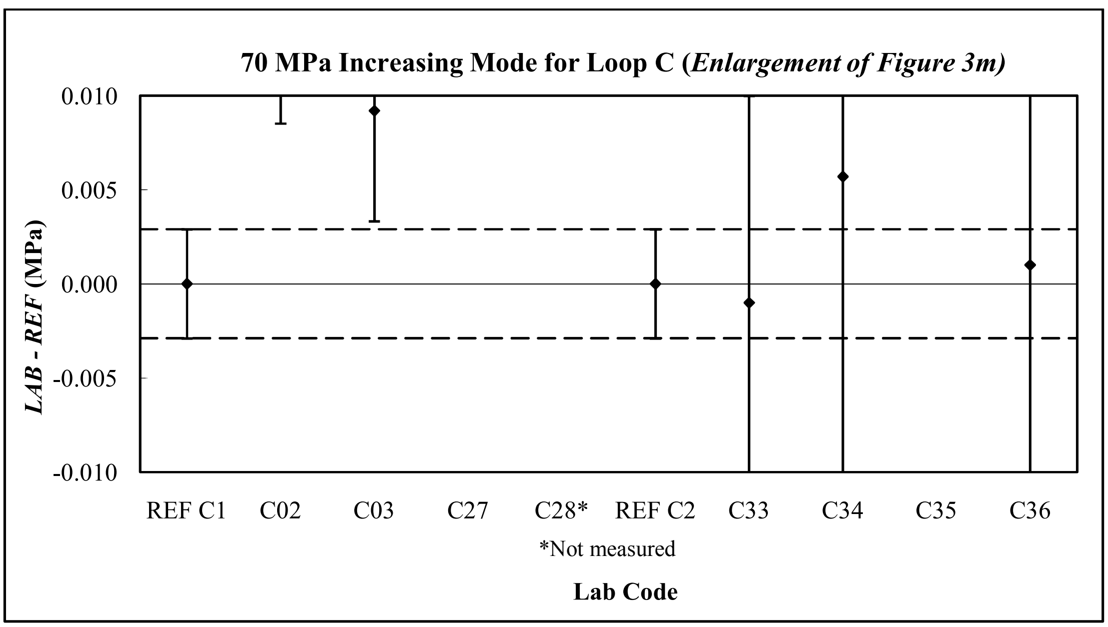


Figure 3n

Figures 4(a to g) *LAB-REF* at Decreasing Mode for Loop A

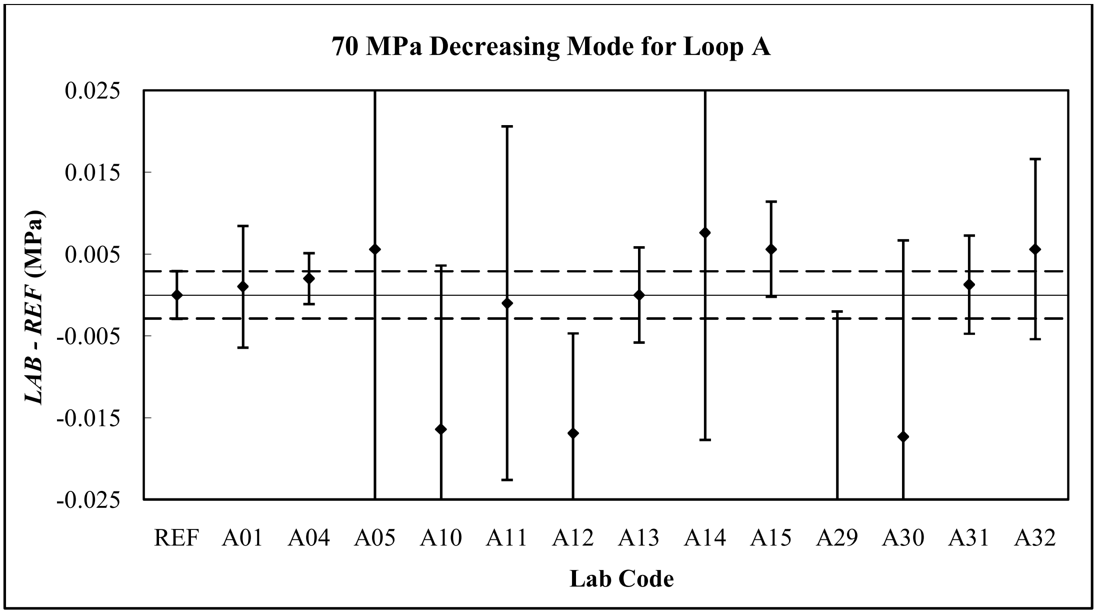


Figure 4a

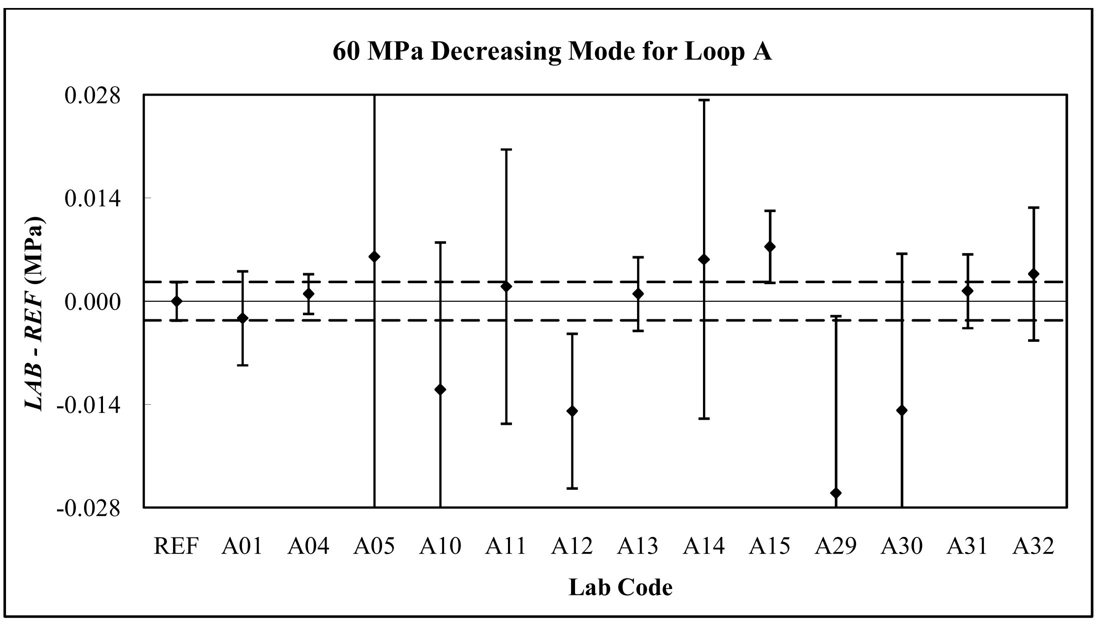


Figure 4b

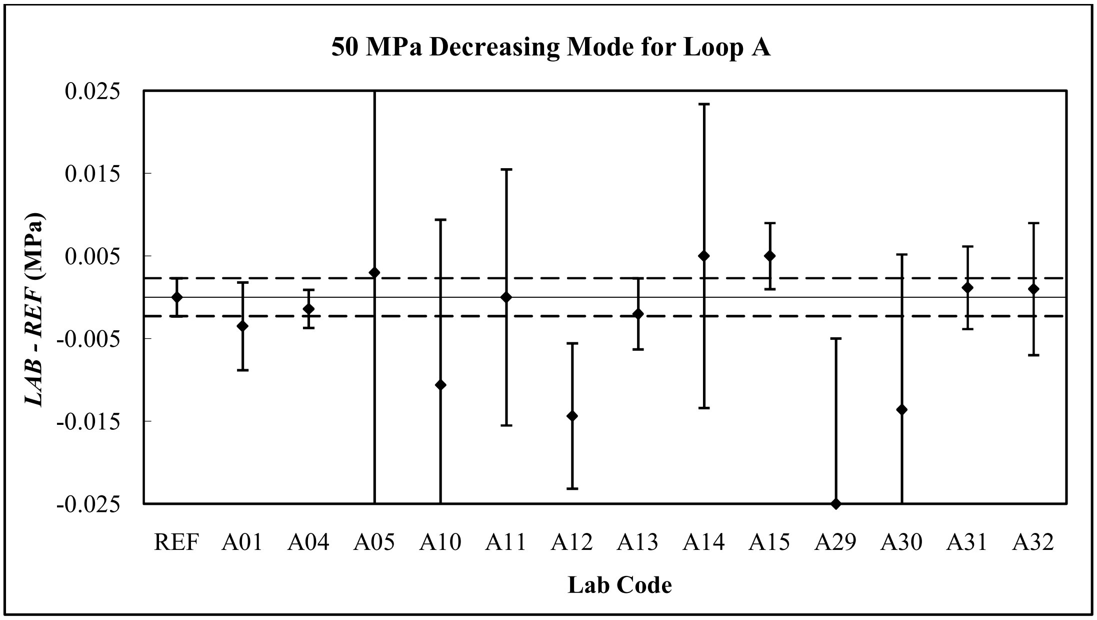


Figure 4c

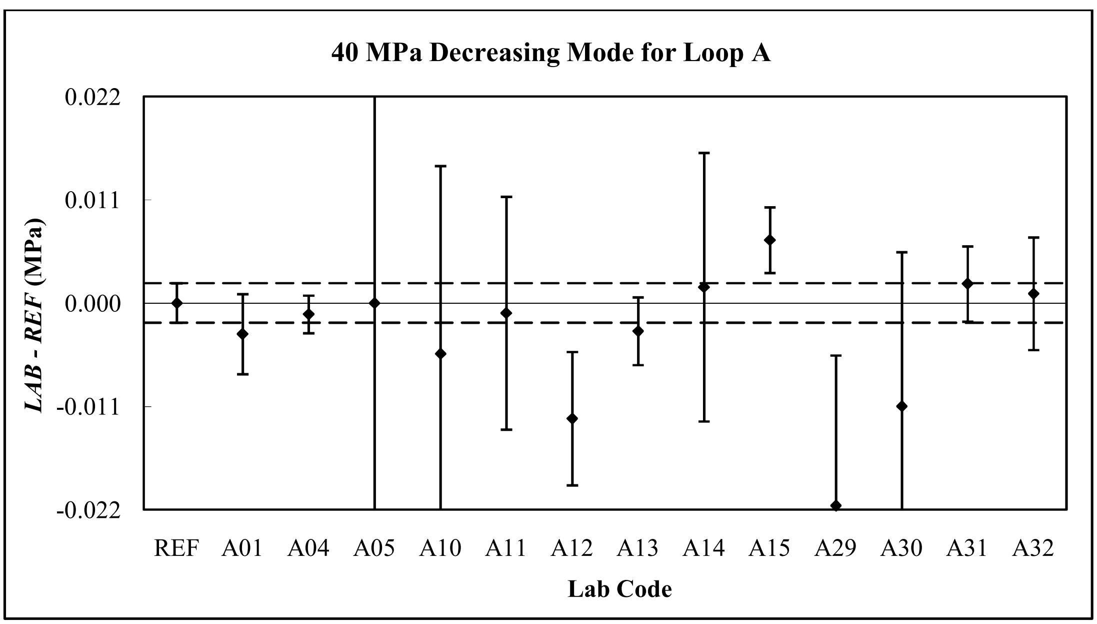


Figure 4d

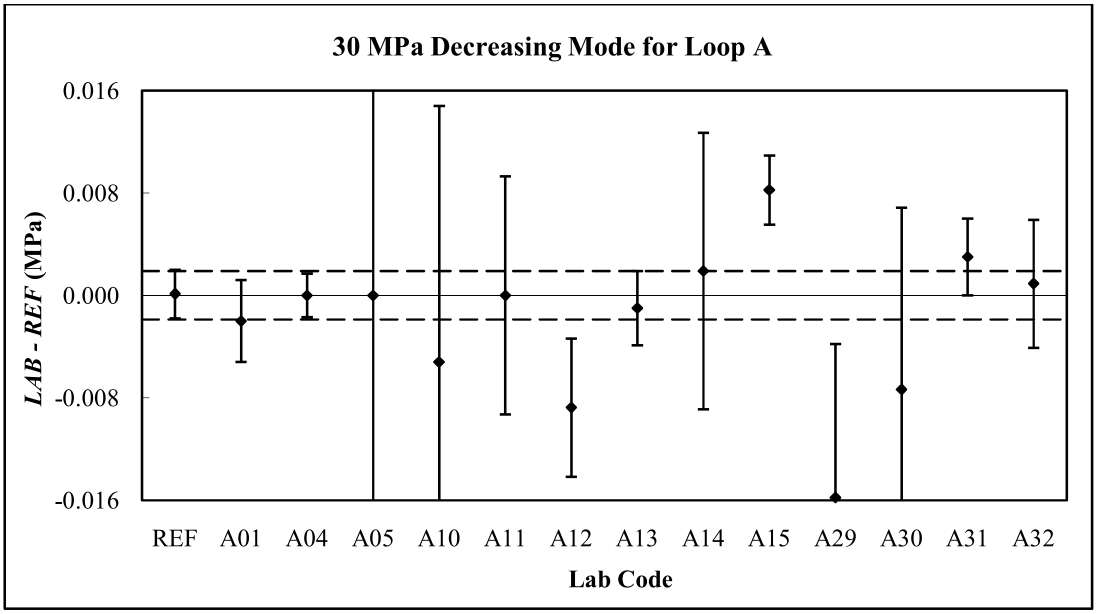


Figure 4e

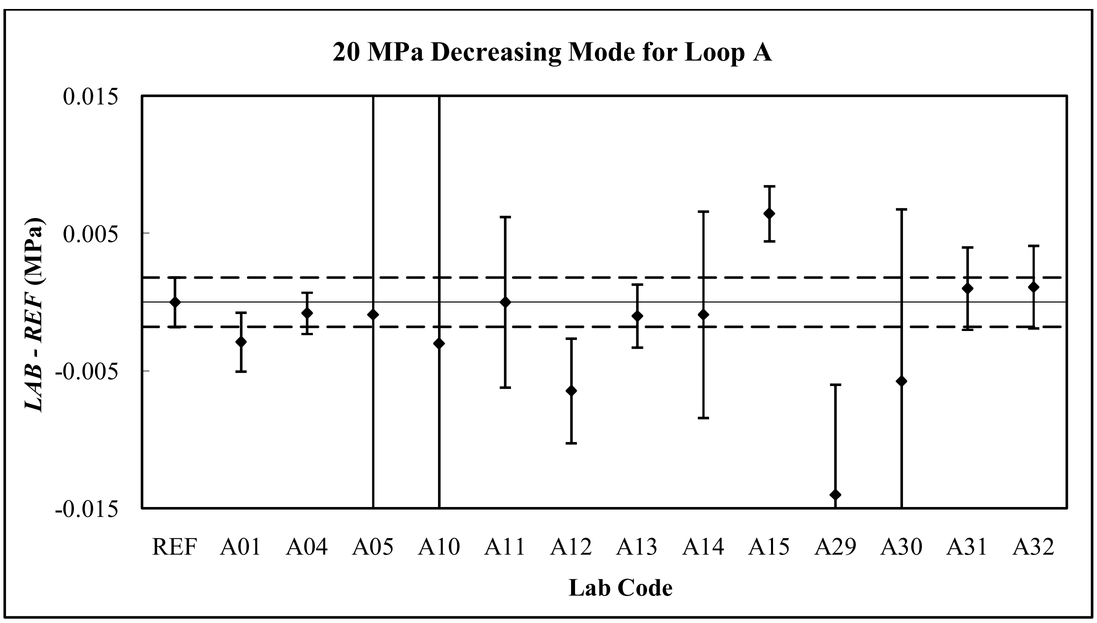


Figure 4f

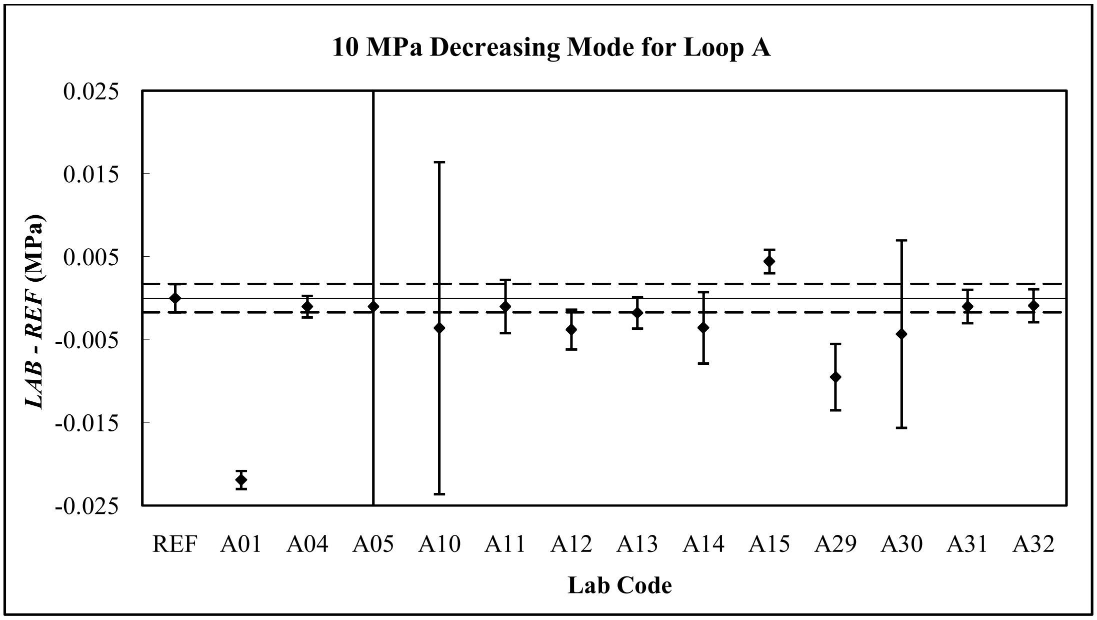


Figure 4g

Figures 5(a to g) *LAB-REF* at Decreasing Mode for Loop B

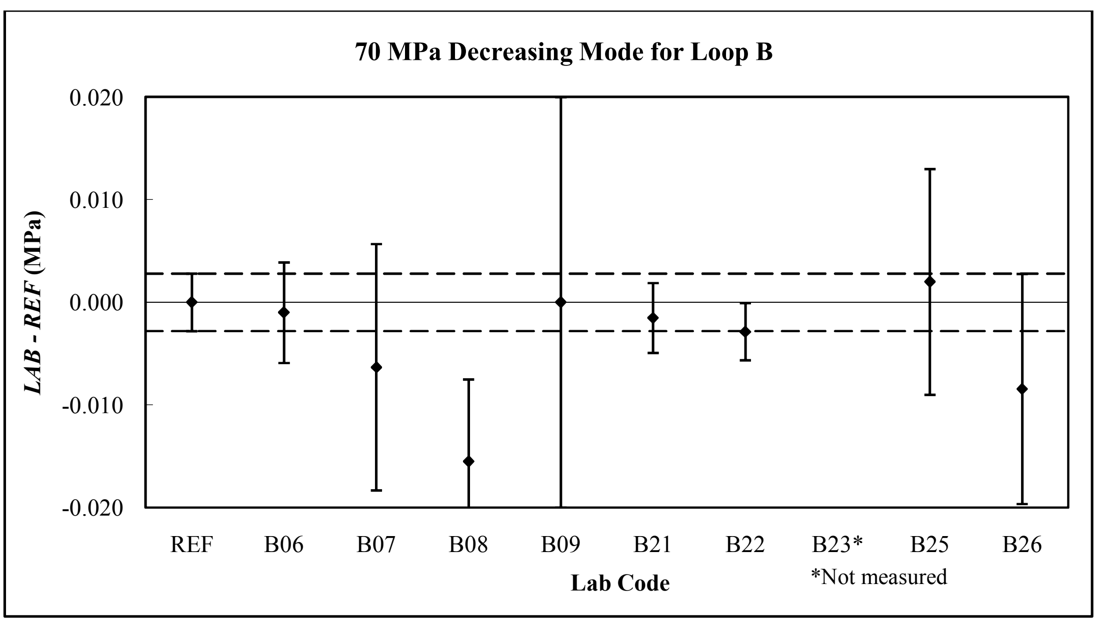


Figure 5a

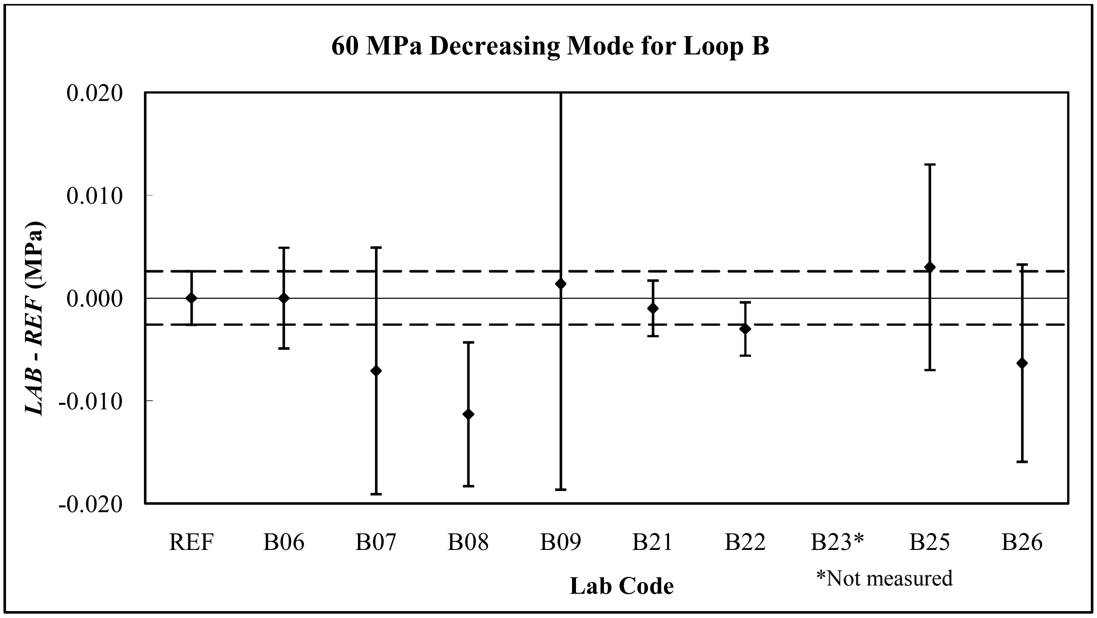


Figure 5b

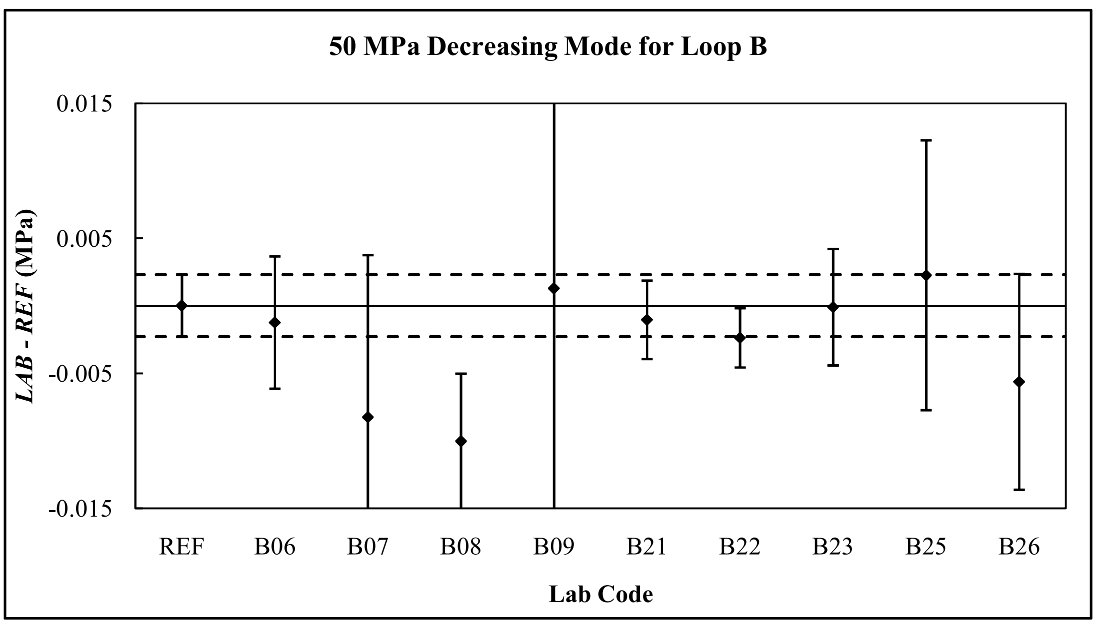


Figure 5c

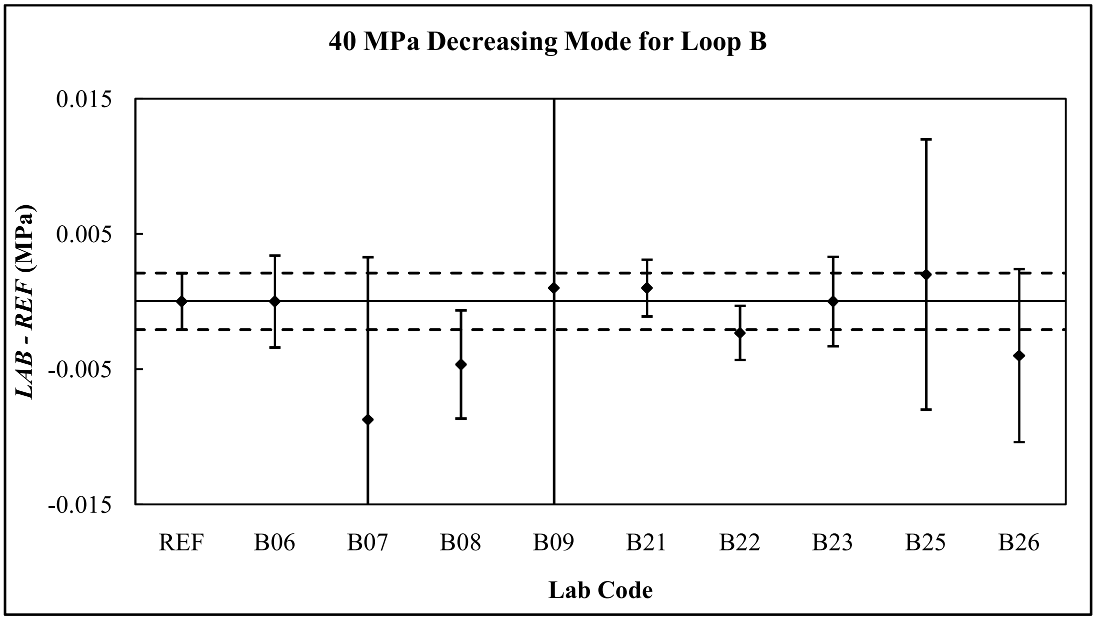


Figure 5d

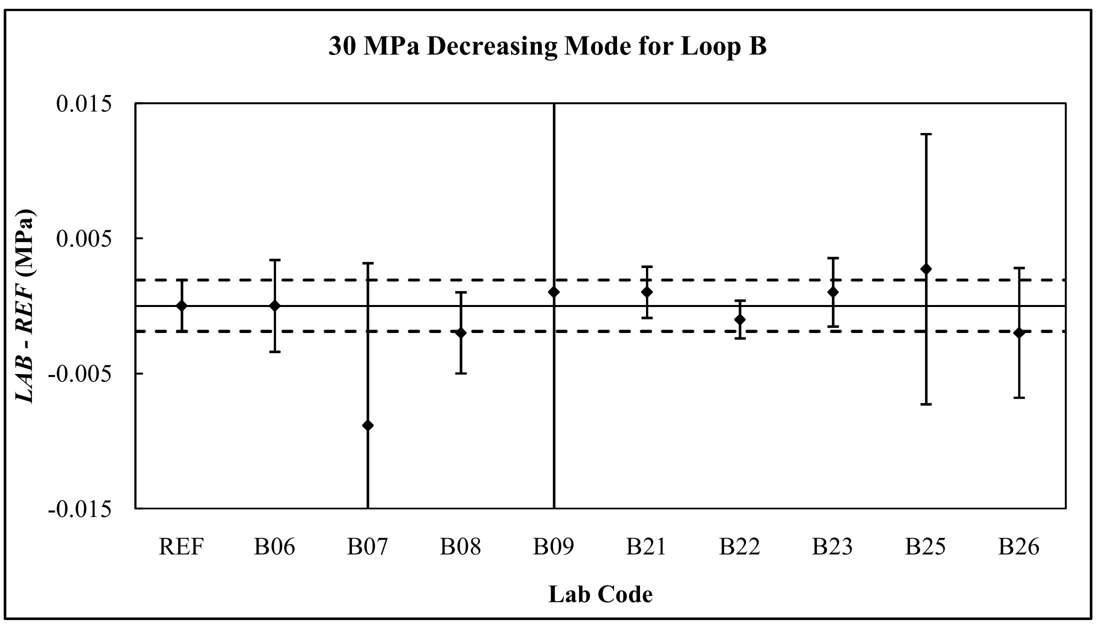


Figure 5e

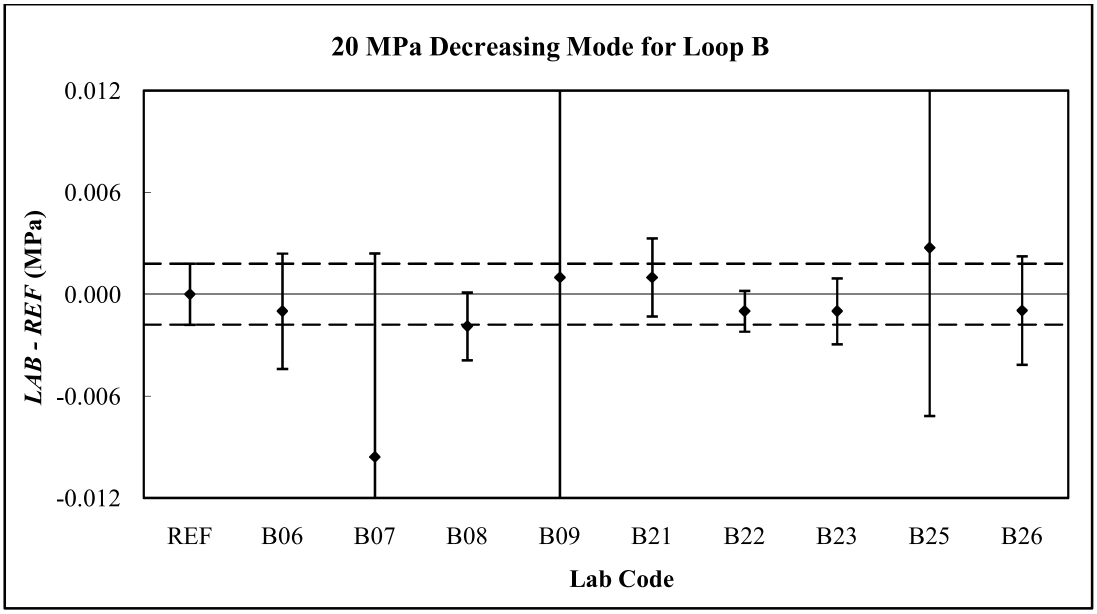


Figure 5f

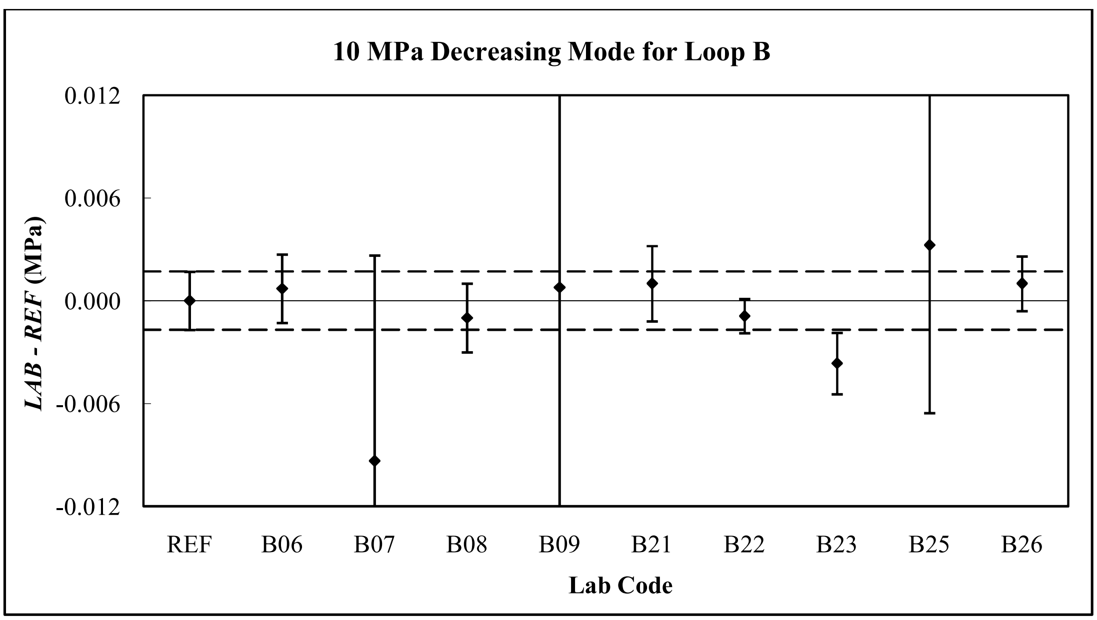


Figure 5g

Figures 6(a to n) *LAB-REF* at Decreasing Mode for LoopC

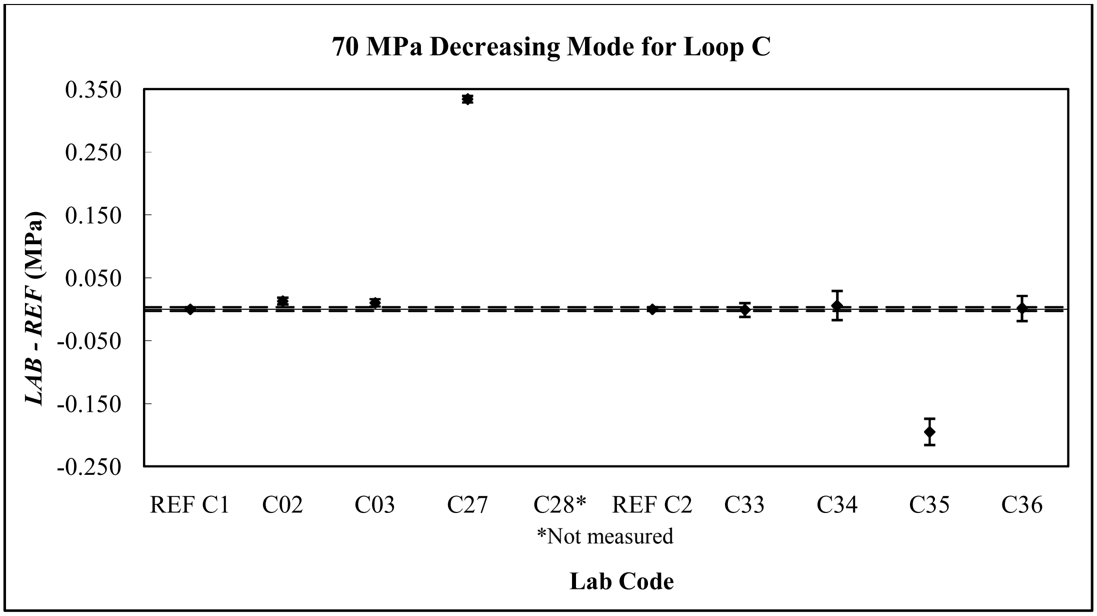


Figure 6a

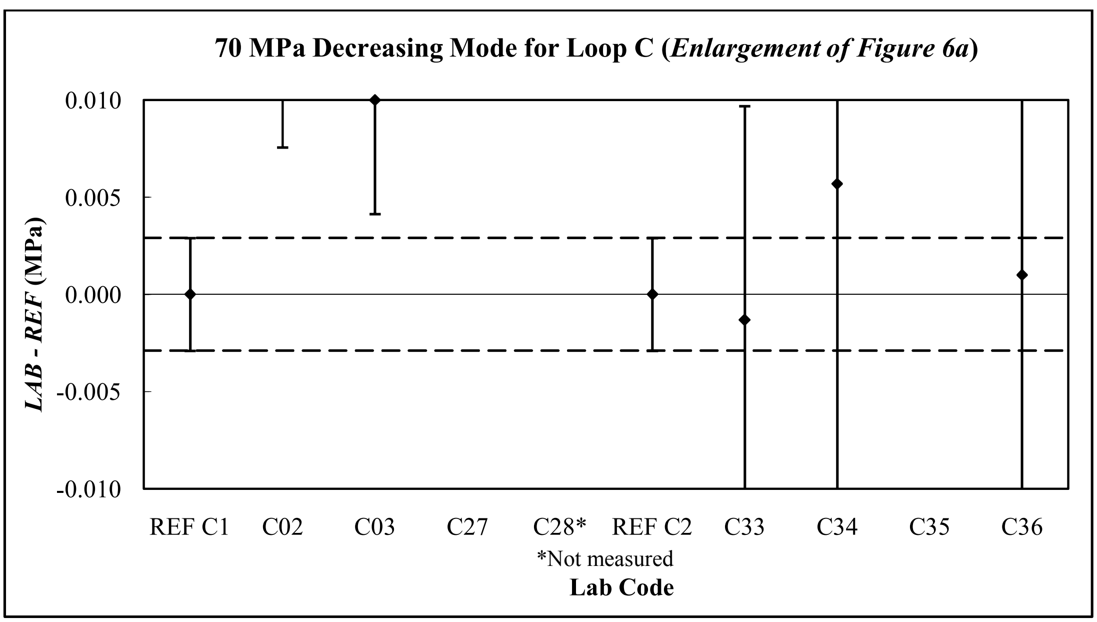


Figure 6b

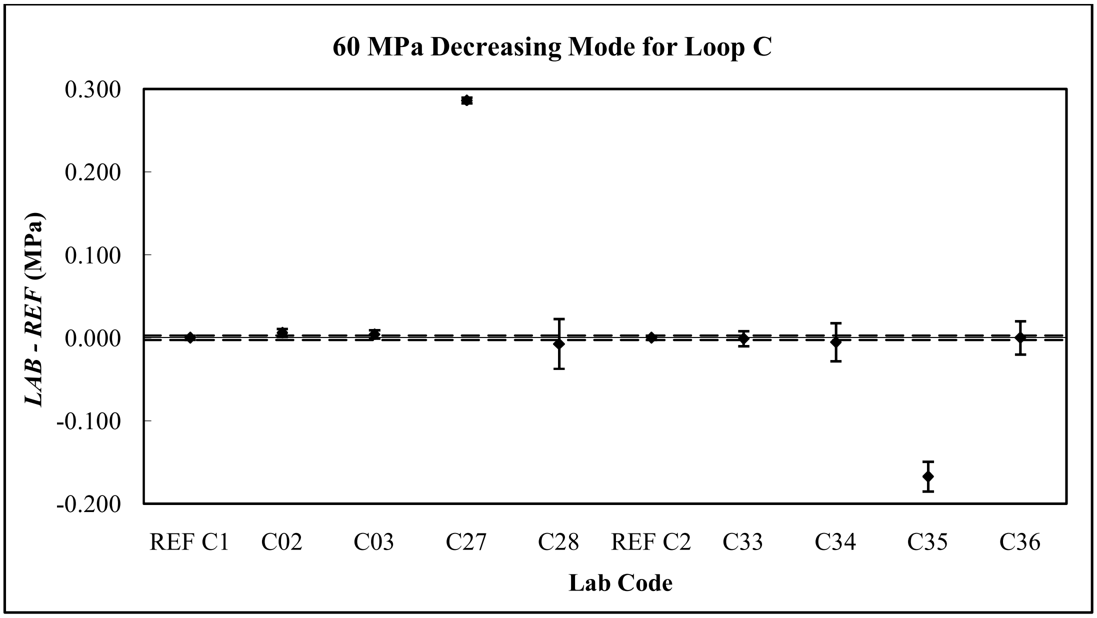


Figure 6c

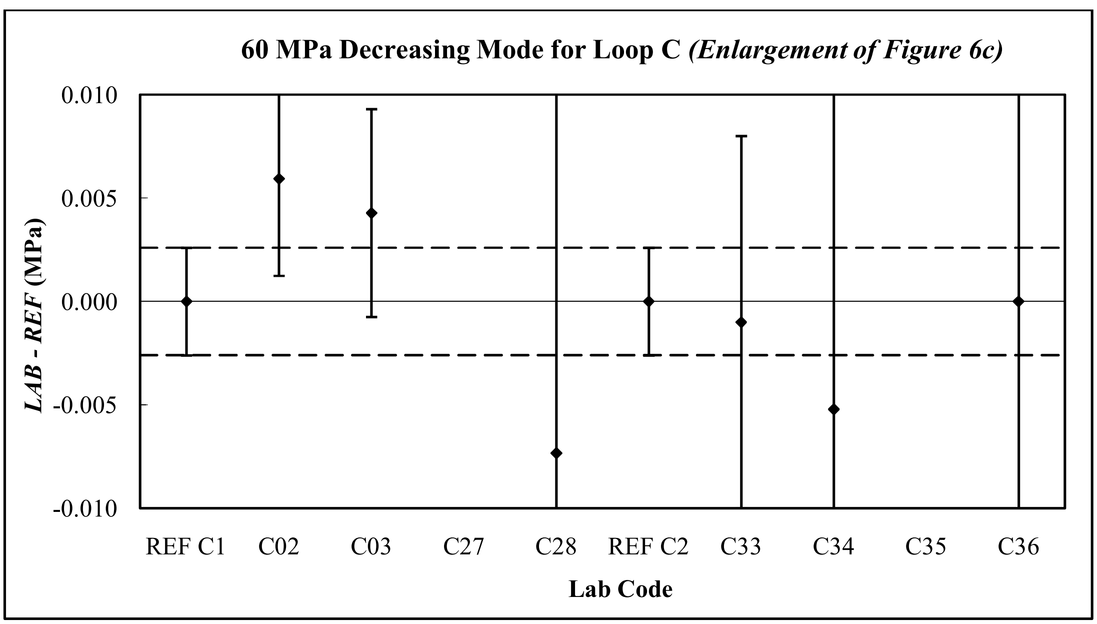


Figure 6d

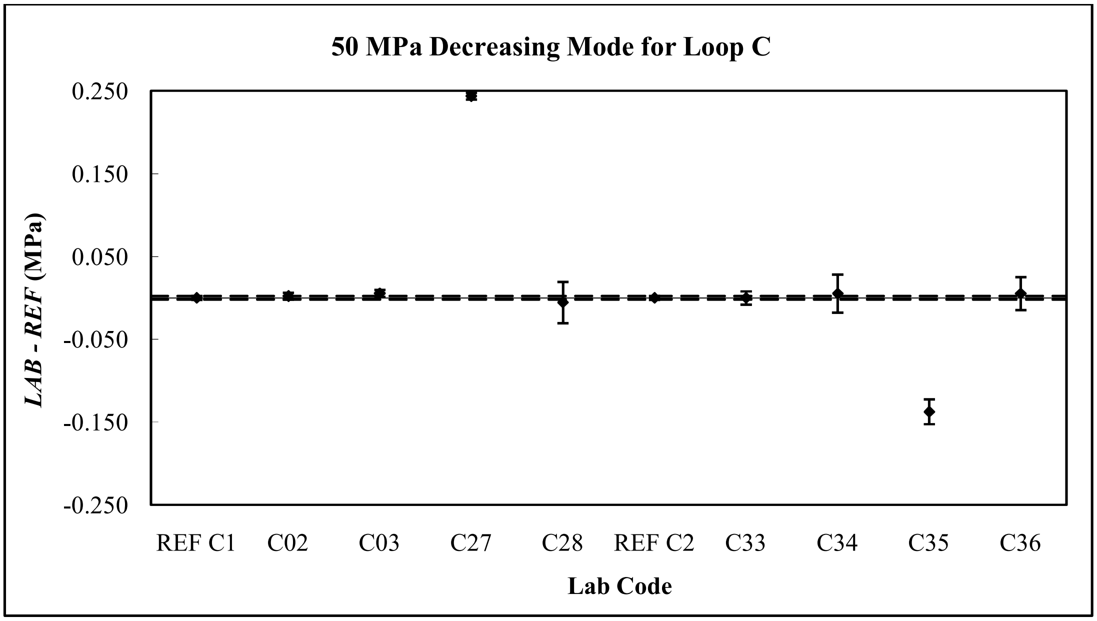


Figure 6e

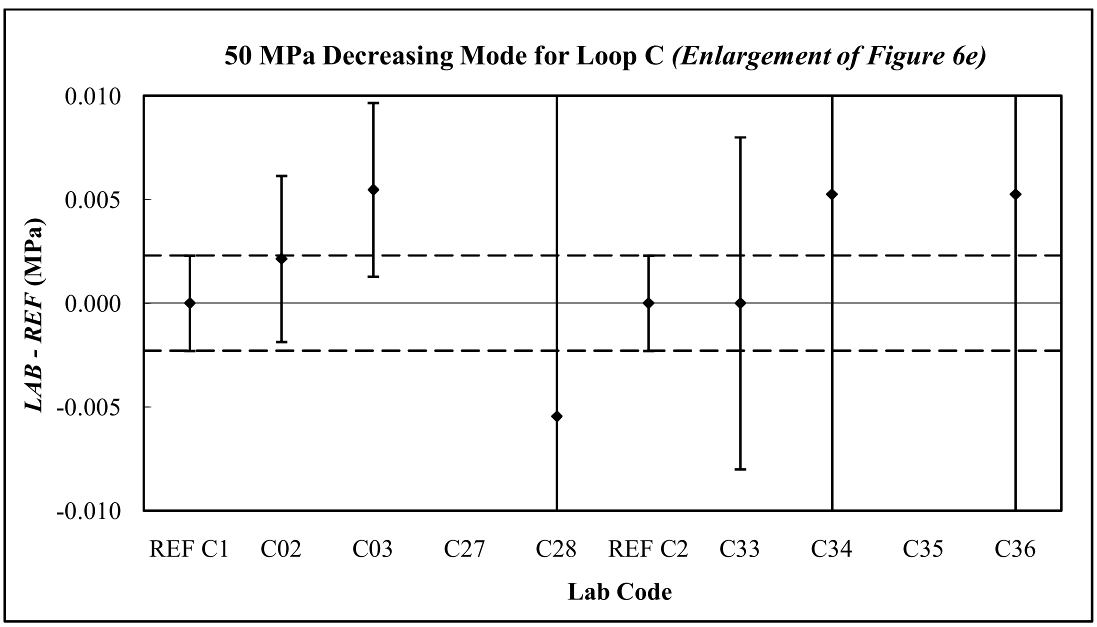


Figure 6f

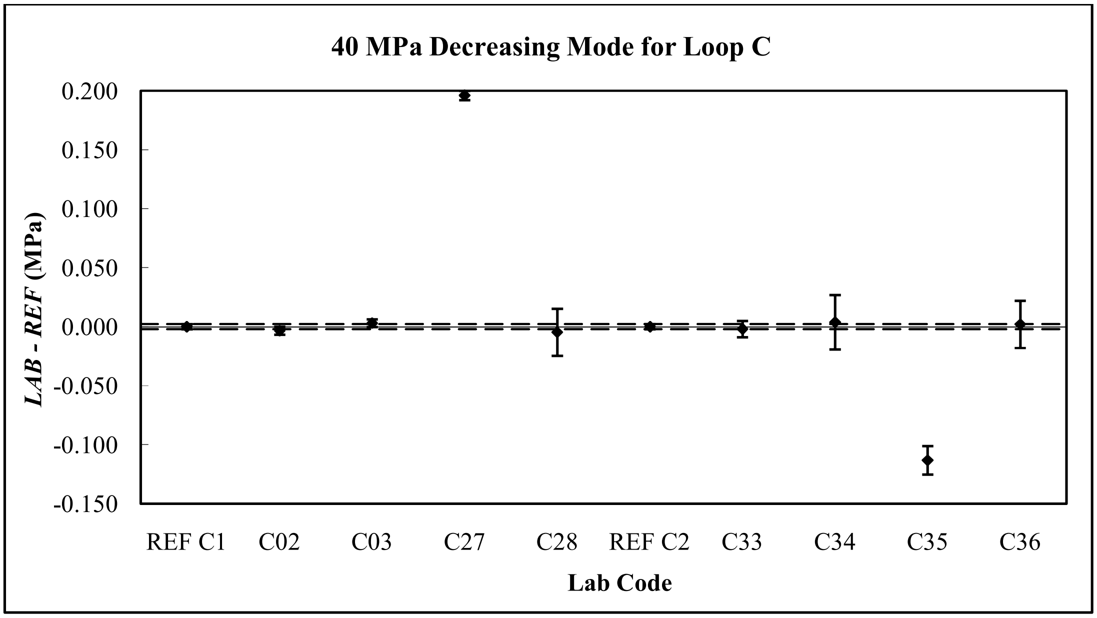


Figure 6g

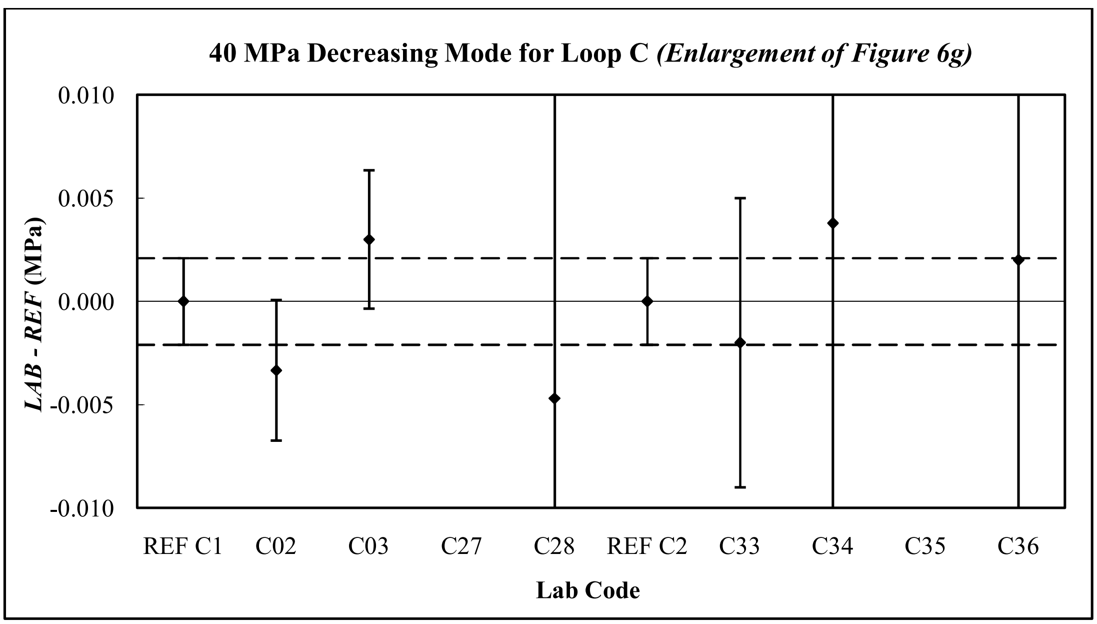


Figure 6h

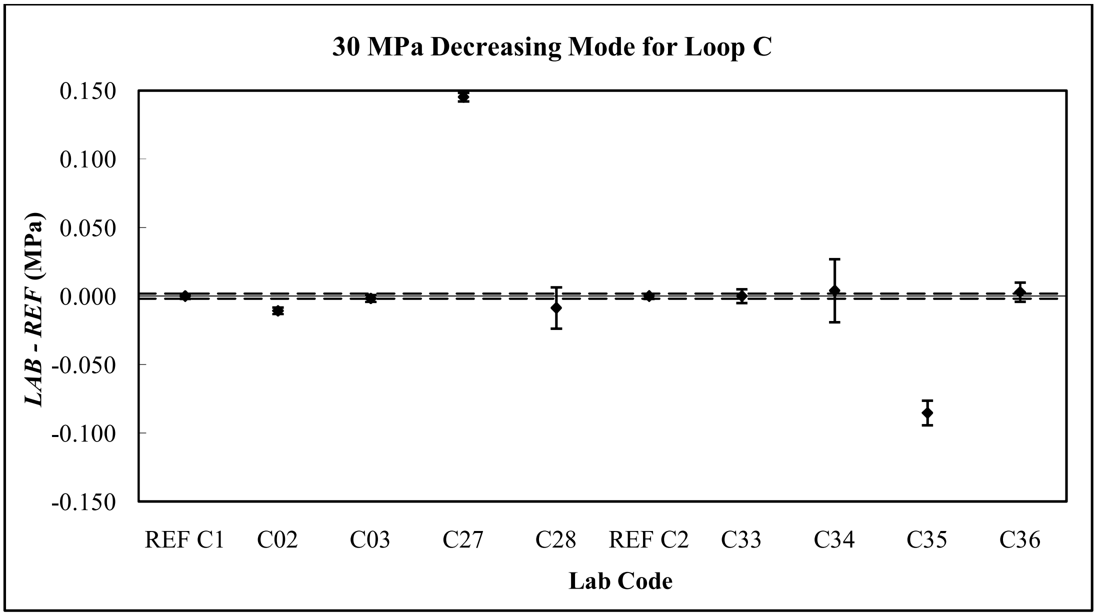


Figure 6i

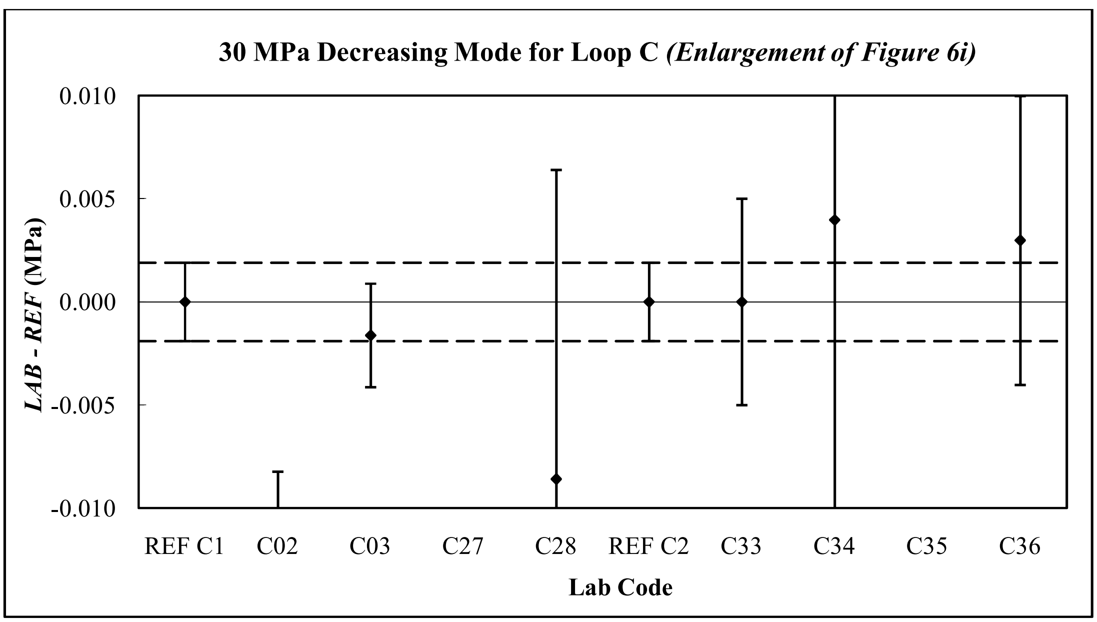


Figure 6j

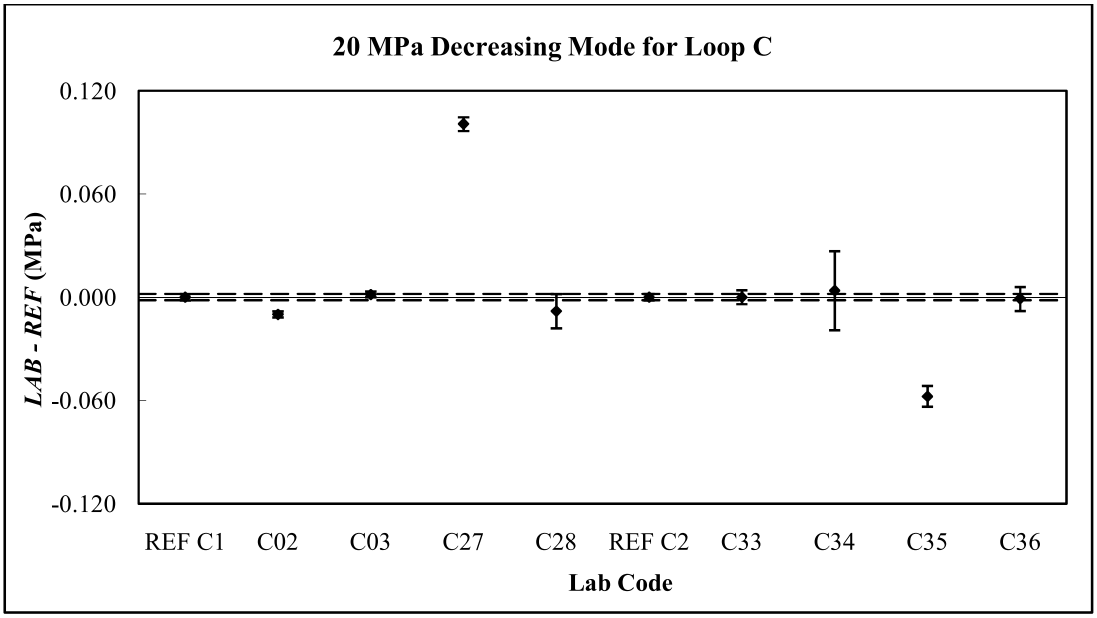


Figure 6k

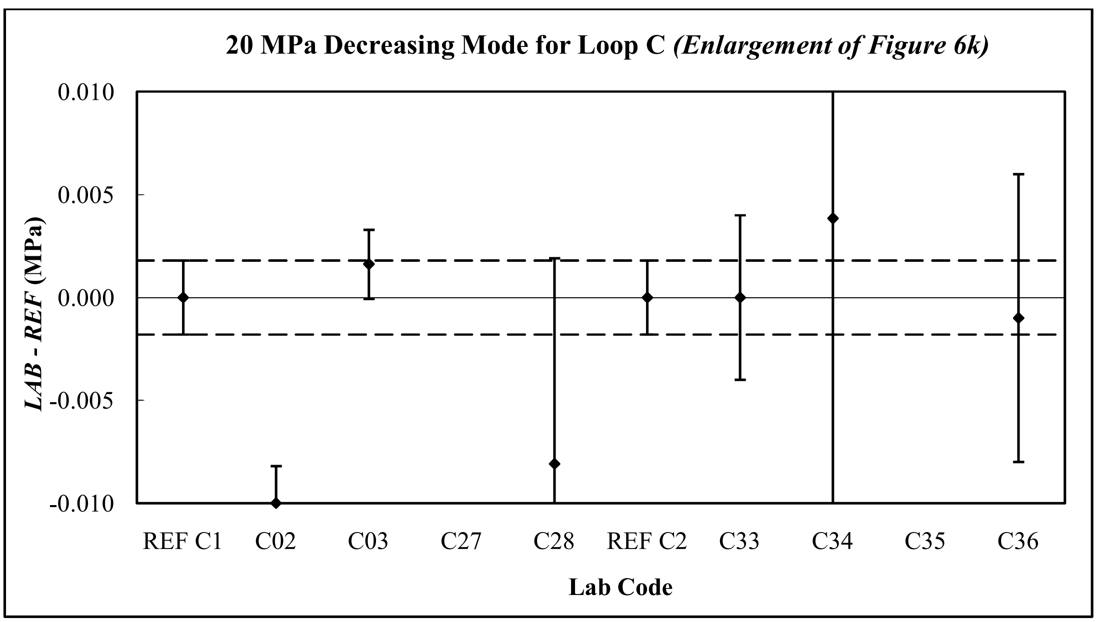


Figure 6l

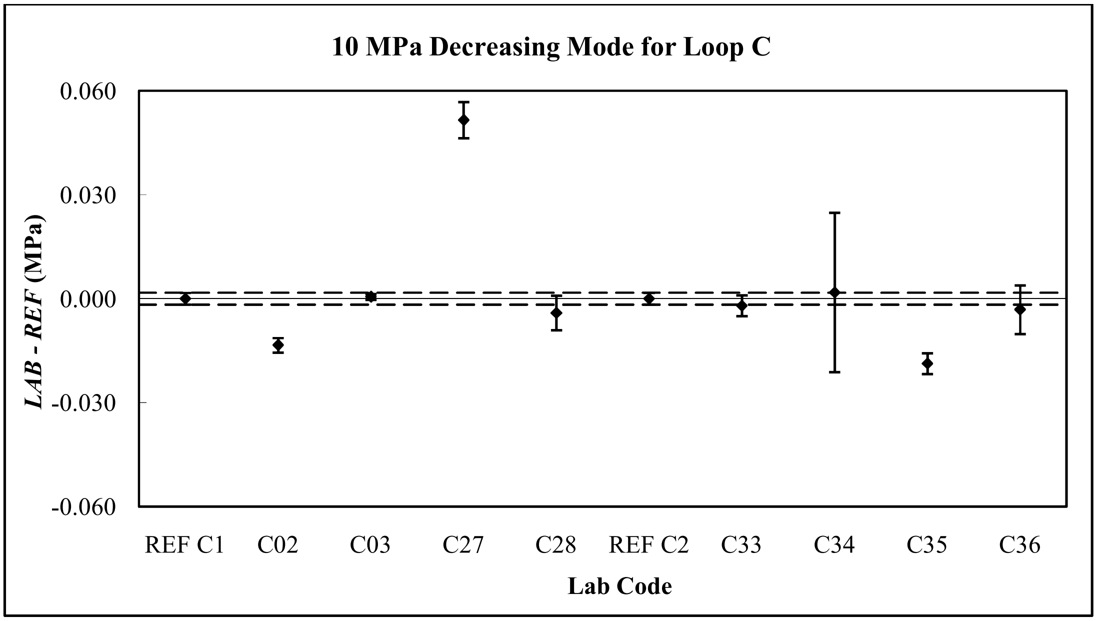


Figure 6m

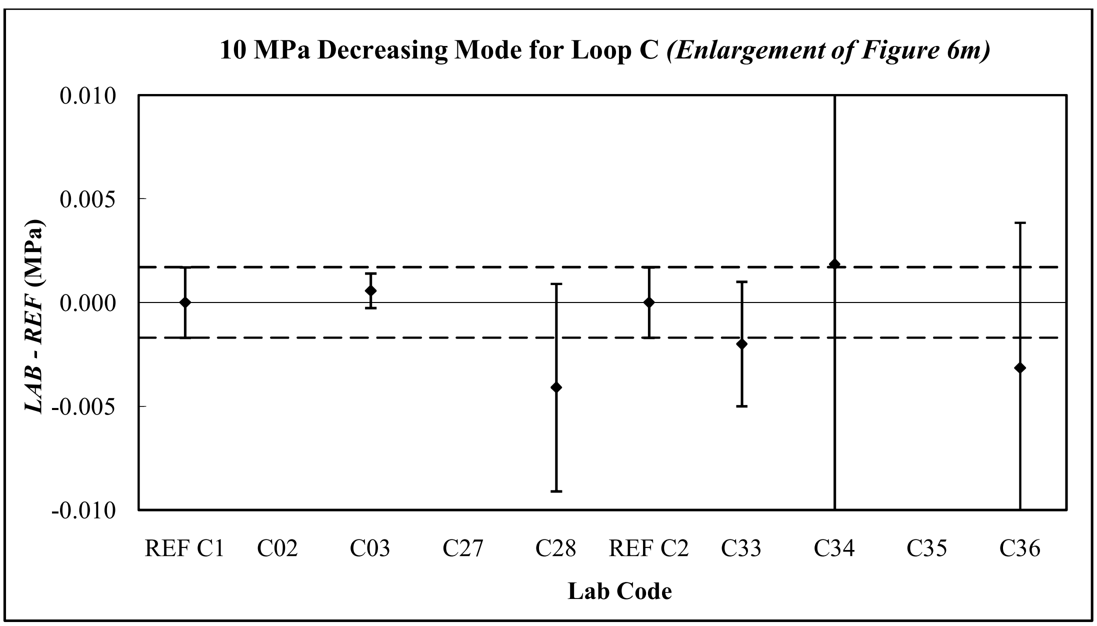


Figure 6n

11. PERFORMANCE OF PARTICIPANTS

Table 3 of $|E_n|$ values shows an overall good performance by the majority of participating laboratories.

Lab codes A12, C27 and C35 have pressure results with $|E_n| > 1.0$ at all points. Lab codes A01, A15, A29, B08, B23, C02 and C03 have one or more pressure results with an $|E_n| > 1.0$.

Lab code A05 has pressure results with all $|E_n| \leq 1.0$, but the measurement uncertainties reported appear to be too large.

Figure 7 below shows the overall performance of the laboratories in terms of E_n values.

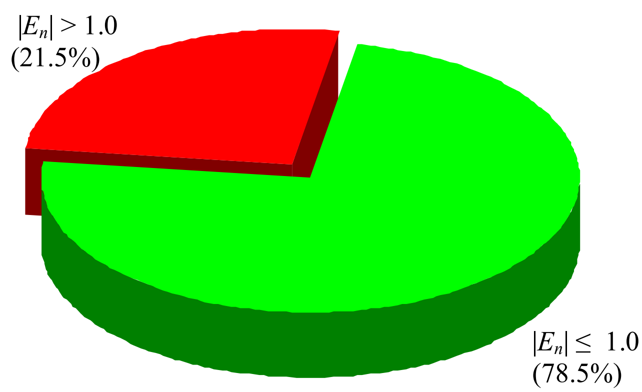


Figure 7 – Summary of 414 Reported Results

The possible reasons that could lead to large differences between the laboratory measurement and the reference value may be attributed to the following:

(i) pressure head correction due to height difference between the laboratory reference and the artefact not applied or incorrectly applied,

(ii) hydraulic system not properly purged of trapped air,

(iii) incorrect gravity value used in the case where the reference standard used is a dead-weight tester and,

(iv) calibration status and reliability of the reference standard used.

12. UNCERTAINTIES OF MEASUREMENT

An example of the uncertainty evaluation of the pressure deviation of the artefact at nominal pressure of 10 MPa is provided in Appendix IV.

There may have been some under-estimation and over-estimation of the overall uncertainty by some laboratories.

Some possible causes of under-estimation could be attributed to:

- non-inclusion of the uncertainty due to the drift of the reference standard used,
- under-estimation of the uncertainty associated with the value of the gravitational acceleration used and,
- non-inclusion of the uncertainties due to the zero drift and resolution of the artifact.

Over-estimation of the overall uncertainty may have been caused by :

- inclusion of the linearity error of the artefact as an uncertainty component,
- inclusion of an uncertainty component due to hysteresis and,
- over-estimation of the uncertainty value due to gravitational acceleration.

13. CORRECTIVE ACTIONS

Details of corrective action are not included in this report. The respective accreditation bodies have to ensure that any laboratory with unsatisfactory performance (i.e. $E_n > 1.0$) under their purview has the problem rectified and procedures to prevent recurrence have been put in place.

14. REFERENCES

1. APLAC PT001 - Calibration Interlaboratory Comparisons Issue No. 5.
2. ISO Guide to the Expression of Uncertainty in Measurement, 1995.
3. EURAMET Guidelines on the Calibration of Electromechanical Manometers, EURAMET/cg-17/v.01, July 2007.
4. ISO/IEC 17025:2005 - General Requirements for the Competence of Testing and Calibration Laboratories.
5. Guideline DKD-R 6-1 Calibration of Pressure Gauges, DKD Edition 01/2003.

APPENDIX I

INSTRUCTIONS TO LABORATORIES AND RESULT SHEETS

APLAC M025 PRESSURE MEASUREMENT

PROFICIENCY TESTING PROGRAMME

CALIBRATION OF
HYDRAULIC PRESSURE CALIBRATOR
(GAUGE MODE)

MEASUREMENT INSTRUCTIONS

July 2009

Table of Contents

APLAC PROFICIENCY TESTING PROGRAMME M025

APLAC M025 CALIBRATION OF
HYDRAULIC PRESSURE CALIBRATOR (GAUGE MODE)

1. Introduction

The purpose of the APLAC M025 Proficiency Testing Programme is to compare the calibration results of accredited laboratories within APLAC in the field of hydraulic pressure measurement up to 70 MPa (gauge mode) where the values of pressure generated by the participating laboratories' standards and the observed readings of the transfer standard; together with the respective measurement uncertainties will be the main basis of comparison. The artefacts for this programme are Druck PC6-IDOS Pressure Calibrators which are four (4) units in total. Three (3) of them will be circulated to the participating laboratories through **three (3) Concurrent Measurement Loops**. One (1) of them will be used as a back-up artefact for any unforeseen circumstances which may happen.

2. Coordinator

The coordinator of this PT Programme is the Department of Standards Malaysia (STANDARDS MALAYSIA). Complete information about the coordinator is as follows:

STANDARDS MALAYSIA
Century Square, Level 1 & 2,
Block 2300, Jalan Usahawan,
63000 Cyberjaya,
MALAYSIA

The contact person for STANDARDS MALAYSIA is:

Mr. Ahmad Razif B. Abd. Rahim
Tel: +603 83191400
Fax : +603 83189339
E-mail: razif@standardsmalaysia.gov.my

3. Reference Laboratory

The reference values of the pressure measurement will be provided by the National Metrology Laboratory, SIRIM Berhad, Malaysia (NML-SIRIM). Complete information about NML-SIRIM is as follows:

National Metrology Laboratory
SIRIM Berhad,
Lot PT 4803, Bandar Baru Salak Tinggi
43900 Sepang, Selangor,
MALAYSIA

The contact person for NML-SIRIM is:

Dr. Wan Abd Malik Wan Mohamed
Tel: +603 87781621
Fax : +603 87781661
E-mail: wanmalik@sirim.my

4. Artefact

Detailed information about the artefacts is as follows:

Model	: IPC6-PRO-0700-C-1
Range	: 0 ~ 70 MPa (gauge mode)
Resolution	: 0.001 MPa
ID No.	: JSM/M/H/08/90-1, JSM/M/H/08/90-2, JSM/M/H/08/90-3 & JSM/M/H/08/90-4
Manufacturer	: GE Sensing, UK
Estimated uncertainty of measurement	: 0.03% of reading

Note:

i) *To prevent the artefact from any damages, qualified metrology personnel shall only handle the artefact with extreme care.*
ii) *All the artefacts were intentionally adjusted/configured for greater errors prior to PT programme, and they are password-protected. This configuration will be maintained throughout this PT programme.*
iii) *The artefact used in this PT programme shall not be modified, adjusted, configured or used for any other purpose other then described in this document, nor given to any party other then the participants in this programme.*

5. Environmental Conditions

Measurement of the environmental conditions such as temperature, atmospheric pressure and relative humidity shall be conducted using appropriate measuring instruments, where they are assumed to be available in all participating laboratories. All these readings shall be reported in the Result Sheet of Appendix F.

6. Reporting of Calibration Results

Please refer to the table below for the details of results submission.

Document	**When to be submitted**	**Submitted to whom**
Completed Appendices: • Appendix E • Appendix F • Appendix G • Appendix H	**Within two (2) weeks after completion of the calibration process**	Accreditation Body (AB), to be forwarded to STANDARDS MALAYSIA

7. Analysis of Results

STANDARDS MALAYSIA will analyse the results and produce interim and final reports in consultation with the reference laboratory.

Appendix A

Instructions to Accreditation Bodies

APLAC PROFICIENCY TESTING PROGRAMME M025

CALIBRATION OF HYDRAULIC PRESSURE CALIBRATOR (GAUGE MODE)

1. EQUIPMENT

On receipt, unpack the audit pack and inspect the artefact for any defects. Complete the attached "*RECEIPT FORM*" and fax/e-mail to STANDARDS MALAYSIA.

Please note, these instructions and attached *Result Sheet* are master copies and must remain in the box from country to country. The national accreditation body should make copies for distribution to the participating laboratories in their country.

2. TRANSPORT

The artefacts can be carried by hand, car or by plane, whatever is considered the safest way.

3. CUSTOMS

NO ATA Carnet is provided with these artefacts. A *Declaration to Customs Officials and Shipping Agents* is enclosed in the plastic envelope attached to the outside of the box. Please make sure it is in place before dispatching to the next country otherwise it will not pass through their Customs authorities. Please attach three (3) extra photocopies of the *Declaration*.

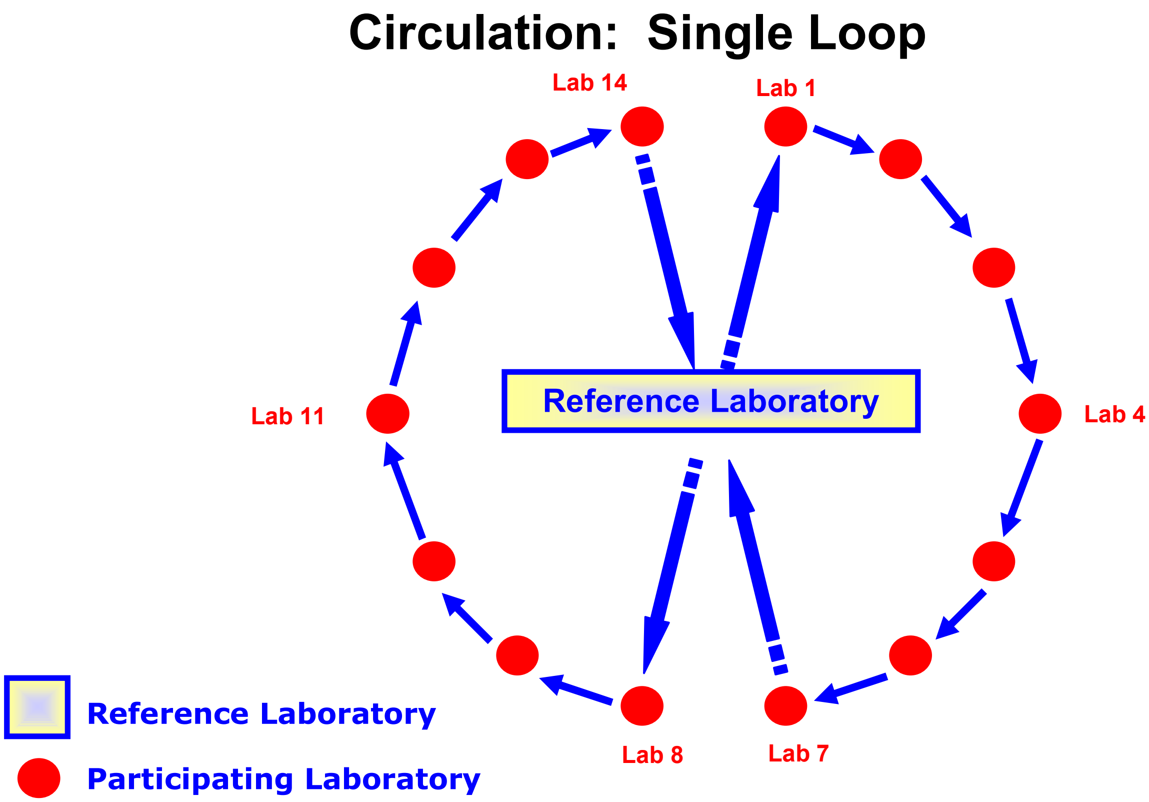
4. MEASUREMENTS TO BE CARRIED OUT

Please refer to INSTRUCTIONS TO LABORATORIES (Appendix D) enclosed. If necessary, these should be translated into the appropriate language by the accreditation body.

5. CIRCULATION SCHEME

At the beginning, middle and end of the circulation scheme, measurements will be performed by the reference laboratory i.e. National Metrology Laboratory, SIRIM Berhad, Malaysia (NML-SIRIM).

Each laboratory will be given one (1) week to perform measurement. It is the responsibility of the accreditation body to make sure that the artefact is dispatched to the next participant by the date specified. One (1) week has been allowed for each international transport and customs clearance. If a delay occurs with one laboratory, then the number of participating laboratories in that particular country should be reduced so that the artefact could leave for the next participating country as scheduled. When the artefact is ready to be dispatched, the participating accreditation body has to fill in the *DISPATCH FORM* (Appendix C) and fax it to the next participating accreditation body and STANDARDS MALAYSIA.



6. DOCUMENTS TO BE SUBMITTED

Within two (2) weeks after completion of the measurement process, participating laboratories are required to fax or send the *Result Sheet* to their accreditation body. The accreditation body is required to ensure that the *Result Sheets* are filled in correctly and in a complete manner. The accreditation body should provide details of any problems/difficulties that their laboratories had encountered. The accreditation body is required to fax/e-mail the documentation to STANDADS MALAYSIA within two (2) weeks after dispatching the artefact.

On receipt of the information, the organising body for this APLAC proficiency testing programme will prepare interim reports on each laboratory which are then sent back to the national accreditation body. A final report will be issued at the end of the programme, where each participating laboratory will only be identified by a **confidential code** number.

7. GENERAL INFORMATION

For general queries, please contact:

Department of Standards Malaysia (STANDARDS MALAYSIA)
Century Square, Level 1 & 2,
Block 2300, Jalan Usahawan,
63000 Cyberjaya,
MALAYSIA

Attention: Mr. Ahmad Razif B. Abd. Rahim
Tel: +603 83191400
Fax : +603 83189339
E-mail: razif@standardsmalaysia.gov.my

Appendix B

Receipt Form

APLAC PROFICIENCY TESTING PROGRAMME M025

CALIBRATION OF HYDRAULIC PRESSURE CALIBRATOR (GAUGE MODE)

In order to monitor the progress of the PT Programme, we kindly ask each accreditation body, on receipt of the artefact, to fill in this RECEIPT FORM and fax/e-mail it to:

Department of Standards Malaysia (STANDARDS MALAYSIA)
Century Square, Level 1 & 2,
Block 2300, Jalan Usahawan,
63000 Cyberjaya,
MALAYSIA

Attention: Mr. Ahmad Razif B. Abd. Rahim
Fax: +603 83189339
e-mail: razif@standardsmalaysia.gov.my

Thank you in advance for your cooperation.

The M025 artefact, ID number ________________ was received on:_____________ (*date*)

After inspection, are the contents damaged? __________
(yes/no)

If yes, is this serious? __________
(yes/no)

Are the contents still suitable for use? __________
(yes/no)

Was there a "*Declaration to Customs Officials and Shipping Agents*" enclosed in the plastic envelope attached to the outside of the case?

____
(yes/no)

Remarks: ____

____

Participating Accreditation Body:

____

Contact Person: ______________________ Fax: _____________________

e-mail: ______________________ Tel: ______________________

Appendix C

Dispatch Form

APLAC PROFICIENCY TESTING PROGRAMME M025
CALIBRATION OF HYDRAULIC PRESSURE CALIBRATOR (GAUGE MODE)

In order to monitor the progress of the PT Programme, we kindly ask each accreditation body, on dispatch of the artefact, to fill in this DISPATCH FORM and fax/e-mail it to:

Department of Standards Malaysia (STANDARDS MALAYSIA)
Century Square, Level 1 & 2,
Block 2300, Jalan Usahawan,
63000 Cyberjaya,
MALAYSIA

Attention: Mr. Ahmad Razif B. Abd. Rahim
Fax: +603 83189339
e-mail: razif@standardsmalaysia.gov.my

and **also** fax/e-mail it to the next participating accreditation body :-
Next Participating
Accreditation Body: ____________________
Contact Person: ____________________
Email: ____________________

Please ensure that the "*Declaration to Customs Officials and Shipping Agents*" is attached to the outside of the case. Thank you in advance for your cooperation.

The M025 artefact, ID number _______________ was dispatched on: ____________ *(date)*

The artefact has been inspected after return from our
laboratories and were found to be in good condition. _______ *(yes/no)*
Please give details of any problems:-

Shipping agent: _________________ Phone: _________________ Fax: ________________

Airwaybill no. (or consignment note no.): ____

Your accreditation body: ____

Contact person: _____________________ Fax: ______________________

e-mail: _________________________ Tel: ______________________

Appendix D

Instructions to Laboratories

1. Equipment

The contents of the audit pack are as follows:

Carrying box	(1)
Artefact	(1) PC6-IDOS Pressure Calibrator
Reserve part	(1) Battery charger
Original Documentation	(1) i.e. this document

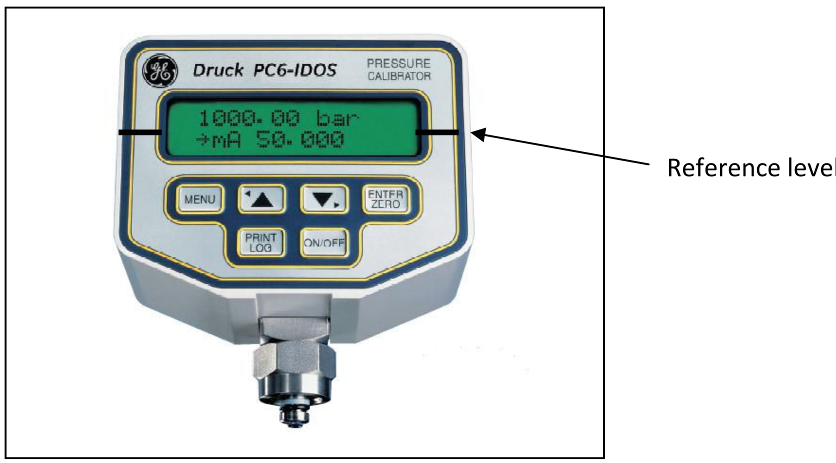


Figure 2 : Photo of artefact

2. On Receipt

On receipt, unpack the audit pack and inspect the artefact for any defects. Read the following instructions before starting the measurement.

1. Please handle the artefact with care.
2. Do not tamper with or adjust the test artefact.
3. Notify the local AB of any damage or erratic operation of the test artefact as soon as possible.

3. Calibration Procedure

i) The right location to install the system shall be wisely chosen in order to reduce any disturbing effects such as vibration, magnetic fields, direct sunlight, air droughts due to air-conditioning system etc.

ii) A stable worktop with appropriate size shall be used to install the system.

iii) Connect the artefact **as close as possible** to the laboratory's pressure standard (preferably dead weight tester) in **vertical position** using suitable adaptors or connectors (if necessary). The bottom fitting connector (pressure port) of the artefact is a standard ¼" NPT male which will suit most of the pressure standards.

iv) A proper valve(s) arrangement in the pressure circuitry system shall be well planned in order to make measurement easier and efficient.

v) Measure the **height difference** between the two reference levels (the reference level of the artefact and the reference level of the standard used) after connecting work completed, and note if down in Appendix E. The reference level of the artefact is located right in the **middle-height of the artefact's display**, which is marked with two black lines on the left and right sides of the display.

vi) A minimum period of twelve (12) hours of acclimatisation process (after receipt) shall be given before starting the actual measurement process.

vii) Start the measurements process by applying pressure at the selected nominal pressures (nominal pressures are based on the artefact's readings and not the pressures generated by the reference standard) which are: **0 MPa, 10 MPa, 20 MPa, 30 MPa, 40 MPa, 50 MPa, 60 MPa and 70 MPa.** Pressures applied shall always be **within 0.1 MPa from the nominal pressure.** A total number of 16 measurements are considered as one (1) complete measurement cycle; i.e. starting from 0.000 MPa to the maximum pressure of 70 MPa for the increasing mode, and subsequently back to the minimum pressure (atmospheric pressure) from the maximum pressure, known as decreasing mode. An illustration of one complete measurement cycle is shown in Figure 1.

viii) Record the actual artefact's reading and the corresponding data/information related to the laboratory's standard at each measurement point using the laboratory's Result Sheet.

ix) Calculate the actual pressure generated by the laboratory's reference standard at the reference level of the artefact and note it down (together with the respective artefact's reading) in the Result Sheet of Appendix F.

x) All participating laboratories are recommended to perform at least five (5) measurement cycles, however **ONLY THE BEST THREE (3) CYCLES ARE REQUIRED TO BE REPORTED** to the coordinating laboratory.

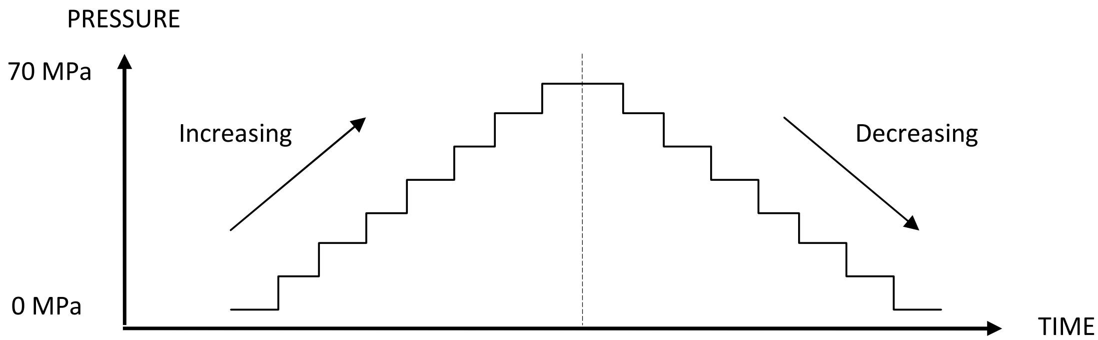


Figure 1: One complete measurement cycle

Note:

i) *If there is no information given in this protocol in certain procedures, the laboratory should follow the normal calibration procedures e.g. in setting up, exercising the pressure gauge and taking of readings etc. for such a calibration, as documented by the laboratory herself .*
ii) *Participating laboratory could use the oil of its pressure standard as a pressure transmitting fluid. However, after the end of the measurements, each participating laboratory shall clean the inner part of the transducer (e.g. using a syringe) and the adapter from the oil used.*
iii) If the participating laboratory only work in units other than MPa (e.g. bar, psi, kgfcm^{-2} etc.), the nearest achievable pressure values which are equivalent to the specified MPa values could be used for the measurement purposes, but they shall always be within 0.1 MPa from the nominal pressure. Actual pressure applied and artefact's reading shall be reported in MPa unit, however the uncertainty of measurement may be reported in MPa or relative to MPa unit (e.g. %R or %FS); therefore an appropriate conversion factor shall be used.
iv) If the artefact does not display 0.000 MPa at the beginning of the measurement cycle (when both of the instruments are exposed to atmospheric pressure after exercising process), zeroing process is necessary. However, a drifted-zero reading displayed by the artefact when both of them are exposed to the atmospheric pressure again in the decreasing mode (at the end of the measurement cycle) is a common phenomenon; this reading shall be taken and reported.
v) In order to ensure that all measurement points measured by participating laboratories are in consistence/standardised manner, the nominal pressure shall be referred to the ***READINGS INDICATED BY THE ARTEFACTS (± 1 bar)*** *e.g. at nominal pressure of 50 MPa, measurement shall be carried out when the artefact reads between 499.00 bar to 501.00 bar.*

WARNING!!!

DO NOT ATTEMPT TO ADJUST, MODIFY OR RE-SET ANY CONFIGURATIONS MADE ON ARTEFACTS EVENTHOUGH THEY ARE PASSWORD PROTECTED

4. Completion of measurements

Upon completion of the measurement, the laboratories are required to inform the respective accreditation body in the country.

5. Documents to be submitted

Within two (2) weeks of the completion of the measurements, participating laboratories are required to send the attached *Result Sheet* (**Appendix F**) to the respective accreditation body. Laboratories are strongly advised to make a copy of those documents for their own records and future references.

In addition to the above, participating laboratories are required to submit *Laboratory Details* **(Appendix E),** *Uncertainty of Measurement* (**Appendix G**) and *Uncertainty Budget Table* (**Appendix H**) which are prepared in accordance with the ISO *Guide to the Expression of Uncertainty in Measurement.* **Participating laboratories are required to prepare uncertainty budget table for each calibration point.**

A final report will be issued at the end of the programme where each laboratory will only be identified by a confidential code number.

6. General Information

For general queries, please contact your accreditation body. Additional information may be obtained from

Department of Standards Malaysia (STANDARDS MALAYSIA)
Century Square, Level 1 & 2,
Block 2300, Jalan Usahawan,
63000 Cyberjaya,
MALAYSIA

Attention: Mr. Ahmad Razif B. Abd. Rahim

Tel: +603 83191400

Fax : +603 83189339

E-mail: razif@standardsmalaysia.gov.my

Appendix E

LABORATORY DETAILS

Name of laboratory	
Measurement Date	From ______________ to ______________
Reference Standard Used	Description: Maker: ______________________________ Model: ______________________________ Serial no.: ____________________________ Calibration date : ______________________ Uncertainty of measurement (k=2) : ________ Calibration due date : ___________________
Local gravity value (particularly important if a deadweight testers is used as a reference standard and if the two (2) reference levels are not at the same height	_______________ ms^{-2} ± _____ ms^{-2}
Pressure transmitting fluid used	Name: _________________________________ Density: __________ kgm^{-3} ± _____ kgm^{-3}
Level difference (between two reference levels i.e. laboratory's standard and artefact)	_____ mm ± _____ mm (* Laboratory standard / artefact is at higher level) * delete as appropriate

Note: Participating laboratory may include additional useful information on the reference standard used if necessary.

Appendix F

RESULT SHEET
(Cycle _____ of _3_)

Nominal Pressure (MPa)	Environmental Conditions	Artefact's Readings (MPa)	Actual Pressure Applied (MPa)
0	Temp: ______°C	0.000	
10	Atm. Pressure: ______kPa		
20	R/H: _________%rh		
30			
40			
50			
60			
70	Temp: ______°C		
70	Atm. Pressure: ______kPa		
60	R/H: _________%rh		
50			
40			
30			
20	Temp: ______°C		
10	Atm. Pressure: ______kPa		
0	R/H: _________%rh		

Notes:

1) Measurement of the environmental conditions shall be taken at the beginning, middle and end of each cycle.

2) The **Actual Pressure Applied** is the calculated pressure generated by the laboratory's reference standard (after appropriate corrections have been applied) at the reference level of the artefact where the formula used to calculate the actual pressure applied shall be given.

Appendix G

UNCERTAINTY OF MEASUREMENT

Nominal Pressure (MPa)	Uncertainty of Measurement (k = 2)	Calibration and Measurement Capability (CMC)
10		
20		
30		
40		
50		
60		
70		
70		
60		
50		
40		
30		
20		
10		

Notes:

1) Uncertainty of Measurement is the uncertainty that the laboratory would state in the calibration certificate (based on the best three measurement cycles submitted) which shall be either in MPa or %R (% of reading) or %FS (% of full scale).

2) Calibration and Measurement Capability (CMC) is the uncertainty for which the laboratory is accredited for (units other than MPa are also acceptable).

Appendix H

Template for Uncertainty Budget Table

Calibration Point: ____ MPa

Quantity	Value	Divisor	Standard Uncertainty	Probability Distribution	Degree of Freedom	Sensitivity Coefficient	Uncertainty Contribution
X_i	x_i		$u(x_i)$		v_i	c_i	$u_i(y)$

Note: Participating laboratory may add additional information if necessary.

Result

Average Value = __________ MPa

Relative Combined Uncertainty, u_c(y) = __________ MPa

Effective degrees of freedom, v_{eff} = __________

Coverage factor, k = __________

Relative Expanded Uncertainty, k x u_c(y) = __________ MPa

Notes:

1. (Add any comments here)

____

____

____

Appendix I

Customs Declaration

This document must stay with the box

ASIA PACIFIC ECONOMIC COOPERATION (APEC)

APLAC PROFICIENCY TESTING PROGRAMME M025

CALIBRATION OF HYDRAULIC PRESSURE CALIBRATOR (GAUGE MODE)

DECLARATION TO CUSTOMS OFFICIALS AND SHIPPING AGENTS

This box contains scientific equipment for an international PT Programme coordinated by on behalf of the Asia Pacific Laboratory Accreditation Cooperation (APLAC). APLAC is classed as a Specialist Regional Body under the APEC Sub-Committee on Standards and Conformity Assessment.

This instrument is of the highest accuracy and should not be dismantled. If a customs inspection is required then please contact the person nominated on the back of this form so that they can be present. Details of the contents of the box are listed below. The contents are not hazardous in any way.

The equipment is for scientific purposes only and no commercial transactions will take place. The box will remain in each country for approximately 2 weeks and then it will be re-exported, hence no import duty or taxes are payable. Details of the participating laboratory accreditation bodies in each country are given on the next page.

CONTENTS OF THE BOX

Item No.	Unit	Description
1.	1	PC6-IDOS Pressure Calibrator, IDNo. : JSM/M/H/08/90-x
2.	1	Battery charger
3.	1	Protocol

COMMERCIAL VALUE: $USD NIL **MATERIAL VALUE:** $USD 2500

TOTAL BOX WEIGHT: 5 kg

BOX DIMENSIONS: 40cm(L)x28cm(W)x15cm(H)

_______________________________________ 27 July 2009

Department of Standards Malaysia DATE

for APLAC Proficiency Testing Committee

APPENDIX II

CIRCULATION SCHEDULE

Table I – Circulation Schedule for Loop A

Economy	Accreditation Body	Number of Labs	Receipt Date	Dispatch Date	No. of Report Submitted
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**-**	**20-07-2009**	**-**
Australia	NATA	2	04-08-2009	24-08-2009	2
Indonesia	KAN	2	11-09-2009	06-10-2009	2
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**10-10-2009**	**28-10-2009**	**-**
Singapore	SAC	2	03-11-2009	19-11-2009	2
Brunei	Calibration Centre, Ministry of Defence	1	03-01-2010	22-02-2010	1
New Zealand	IANZ	2	12-03-2010	29-03-2010	2
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**07-04-2010**	**19-07-2010**	**-**
Malaysia	STANDARDS MALAYSIA	4	19-07-2010	06-09-2010	4
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**06-09-2010**	**-**	**-**

Table II – Circulation Schedule for Loop B

Economy	Accreditation Body	Number of Labs	Receipt Date	Dispatch Date	No. of Report Submitted
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**-**	**20-07-2009**	**-**
Philippines	Philippine Accreditation Office	1	Not informed	Not informed	1
Japan	IAJapan, NITE	2	04-09-2009	24-09-2009	2
Japan	JAB	1	Not informed	05-10-2009	1
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**12-10-2009**	**03-11-2009**	**-**
Hong Kong	HKAS	1	Not informed	12-11-2009	1
China	CNAS	2	16-11-2009	09-12-2009	2
Thailand	Laboratory Accreditation Group 3, Thai Industrial Institute	2	Not informed	Not informed	2
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**22-01-2010**	**-**	**-**

Table III – Circulation Schedule for Loop C

Economy	Accreditation Body	Number of Labs Nominated	Receipt Date	Dispatch Date	No. of Report Submitted
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**-**	**20-07-2009**	**-**
USA	NVLAP	2	10-08-2009	Not informed	2
USA	ACLASS	2	10-09-2009	Oct. 2009	0
USA	A2LA	1	04-11-2009	Nov. 2009	1
USA	LAB	1	02-12-2009	15-12-2009	1
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**05-01-2010**	**25-01-2010**	**-**
Vietnam	BOA	1	29-01-2010	Mar. 2010	0
Mexico	ema	1	Withdraw participation		
India	NABL	2	Not informed	June 2010	*0
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**01-07-2010**	**15-07-2010**	**-**
Malaysia	STANDARDS MALAYSIA	4	16-07-2010	01-10-2010	4
Malaysia	**NML-SIRIM (Ref. Lab)**	**-**	**03-10-2010**	**-**	**-**

Note: * Measurements were unable to be performed due to malfunction of the artefact upon receipt by the accreditation body.

APPENDIX III

REFERENCE VALUES & UNCERTAINTIES

Table I - Reference Values for Artefacts A, B and C

Artefact	Nominal Pressure (MPa)	Reference Values (MPa)	Uncertainty (MPa)
A	10	10.0210	0.0017
	20	20.0438	0.0018
	30	30.0648	0.0019
	40	40.0855	0.0021
	50	50.1052	0.0023
	60	60.1247	0.0026
	70	70.1456	0.0029
	70	70.1456	0.0029
	60	60.1247	0.0026
	50	50.1035	0.0023
	40	40.0837	0.0021
	30	30.0639	0.0019
	20	20.0421	0.0018
	10	10.0201	0.0017
B	10	10.0229	0.0017
	20	20.0443	0.0018
	30	30.0646	0.0019
	40	40.0864	0.0021
	50	50.1063	0.0023
	60	60.1260	0.0026
	70	70.1472	0.0028
	70	70.1472	0.0028
	60	60.1260	0.0026
	50	50.1063	0.0023
	40	40.0863	0.0021
	30	30.0663	0.0019
	20	20.0451	0.0018
	10	10.0238	0.0017
C1	10	10.0227	0.0017
	20	20.0456	0.0018
	30	30.0666	0.0019
	40	40.0898	0.0021
	50	50.1104	0.0023
	60	60.1291	0.0026
	70	70.1509	0.0028
	70	70.1509	0.0028
	60	60.1299	0.0026
	50	50.1121	0.0023
	40	40.0907	0.0021
	30	30.0657	0.0019
	20	20.0473	0.0018
	10	10.0236	0.0017

Table I - Reference Values for Artefacts A, B and C (Continued)

C2	10	10.0219	0.0017
	20	20.0439	0.0018
	30	30.0640	0.0019
	40	40.0838	0.0021
	50	50.1053	0.0023
	60	60.1248	0.0026
	70	70.1457	0.0029
	70	70.1457	0.0029
	60	60.1248	0.0026
	50	50.1053	0.0023
	40	40.0838	0.0021
	30	30.0640	0.0019
	20	20.0438	0.0018
	10	10.0219	0.0017

Notes :

(i) The reference value at each measurement point in group C1 is the average of two (2) results for Artefact C (before repair)
Corresponding Labs : C02, C03, C27 & C28

(ii) The reference value at each measurement point in group C2 is the average of two (2) results for Artefact C (after repair)
Corresponding Labs : C33, C34, C35 & C36

APPENDIX IV

UNCERTAINTY BUDGET TABLE

1. REFERENCE LABORATORY STANDARD

The laboratory standard used as the reference was a pressure balance produced by *Desgranges et Huot* with details and properties as shown below.

Manufacturer	Model	Serial Number	Comments
Desgranges et Huot	5301	Pressure balance – 6585 Piston-cylinder assembly – 6587	It was used as a reference standard in APMP.M.P-K7.1 comparison

Measurement range in MPa	70
Material of piston	tungsten carbide alloy
Material of cylinder	tungsten carbide alloy
Operation mode, free-deformation or controlled-clearance	free-deformation
Zero-pressure effective area (A_0) at reference temperature in mm^2	5.688426
Relative uncertainty of A_0 in 10^{-6}	13
Pressure distortion coefficient (λ) in Pa^{-1}	$1.03\text{x}10^{-12}$
Standard uncertainty of λ in Pa^{-1} (k=1)	$5.29\text{x}10^{-14}$
Linear thermal expansion coefficient of piston (α_p) in °C^{-1}	4.5
Linear thermal expansion coefficient of cylinder (α_c) in °C^{-1}	4.5
Reference temperature (t_0) in °C	20
Local gravity (g) in ms^{-2}	9.78059338
Relative uncertainty of g in 10^{-6}	0.1
Working fluid	di(2)-ethyl-hexyl-sebacate
Height difference between laboratory standard (LS) and artefact (h, positive if LS is higher than artefact) in mm	-48.0

2. STANDARD UNCERTAINTY OF PRESSURE GENERATED BY THE REFERENCE LABORATORY

The pressure generated by the reference laboratory at the reference level of the artefact, P_{std} has been calculated using the following equation:

$$P_{std} = \frac{m_p g_l (1 - \rho_a / \rho_p) + (m - m_p) g_l (1 - \rho_a / \rho_w) + \Gamma . C}{A_{tr} \{1 + (\alpha_p + \alpha_c)(t - 20)\} \{1 + \lambda (P - p_o)\}} + (\rho_f - \rho_a) . g_l . \Delta H$$

where:

P_{std} is the pressure generated by the laboratory standard at the reference level of the artefact (Pa)

p_o is the atmospheric pressure *(Pa)*,

m is the total mass loaded on laboratory standard (including the mass of piston) *(kg)*,

m_p is the mass of piston of laboratory standard *(kg)*,

g_l is the acceleration due to the local gravity (m/s^2),

ρ_a is the density of ambient air (kg/m^3),

ρ_w is the density of weights of laboratory standard (kg/m^3),

ρ_p is the density of piston of laboratory standard (kg/m^3),

Γ is the surface tension of the lubricating fluid *(N/m)*,

C is the circumference of the piston *(m)*,

A_{tr} is the effective area of the piston-cylinder unit at atmospheric pressure and at 20 °C (m^2),

α_p is the linear thermal expansion coefficient of piston of laboratory standard $(/^oC)$,

α_c is the linear thermal expansion coefficient of cylinder of laboratory standard $(/^oC)$,

t is the temperature of the piston-cylinder unit of laboratory standard $(/^oC)$,

λ is the pressure distortion coefficient of the effective area *(/Pa)*,

ρ_f is the density of pressure transmitting fluid (kg/m^3),

ΔH is the difference in height of two reference levels (artefact and laboratory standard): $\Delta H = h_1 - h_2$ *(m)*.

The calculation of the combined standard uncertainty is based on the ISO Guide to the Expression of Uncertainty in Measurement, 1995. The list of the input quantities, their standard uncertainties and relationships for the outputs are given in Table I.

Table I –Uncertainty Budget of Pressure Generated (10 MPa)

Parameter	**Unit**	**Standard Uncertainty**	**Probability Distribution**	**Degree of Freedom**	**Sensitivity Coefficient** $\mid \partial P/\partial x_i \mid$		$\mid\partial P/\partial x_i\mid$ **u(x_i)**	
x_i		$u(x_i)$		ν			**Pa**	***ppm***
Mass of weights and piston; m (NML-SIRIM)	*ppm*	2.50E+00	Normal	inf.	P/m	1.72E+06	25.06	2.51
Acceleration due to gravity, g_l (KRISS, Korea)	ms^{-2}	1.00E-07	Normal	inf.	P/g_l	1.02E+06	0.10	0.01
Density of weights; ρ_w	kgm^{-3}	5.77E+01	Rectangular	50	$P(\rho_a/\rho_w^2)/(1-\rho_a/\rho_w)$	1.88E-01	10.86	1.09
Density of piston; ρ_p	kgm^{-3}	8.66E+01	Rectangular	50	$P(m_p/m)(\rho_a/\rho_p^2)/(1-\rho_a/\rho_w)$	1.80E-03	0.16	0.02
Density of ambient air; ρ_a	kgm^{-3}	1.22E-02	Triangular	200	$(P/\rho_w)/(1-\rho_a/\rho_w)$	1.27E+03	15.50	1.55
Linear thermal expansion coefficient of piston; α_p	$^oC^{-1}$	1.73E-07	Rectangular	50	$P(t-t_r)$	2.51E+07	4.34	0.43
Linear thermal expansion coefficient of cylinder; α_c	$^oC^{-0}$	1.73E-07	Rectangular	50	$P(t-t_r)$	2.51E+07	4.34	0.43
Temperature of PCA ; t (NML-SIRIM)	^oC	1.15E-01	Triangular	inf.	$P(\alpha_p+\alpha_c)$	9.02E+01	10.42	1.04
Effective Area (20ºC, 1 atm); A_{tr} (BNM-LNE)	ppm	6.5	Normal	inf.	P/A_{tr}	1.76E+12	65.00	6.50
Pressure distortion coefficient; λ (BNM-LNE)	Pa^{-1}	5.29E-14	Normal	inf.	$P(P-p_o)$	1.00E+14	5.31	0.53
Pressure generated by reference standard (BNM-LNE), P	*ppm*	1.50E+01	Normal	inf.	-	1	150.00	15.00
Head Correction : Density of pressure-transmitting fluid; ρ_f	kgm^{-3}	5.77E+01	Rectangular	inf.	$g_l \Delta H$	4.69E-01	27.10	2.71
Head Correction : Acceleration due to gravity, g_l	ms^{-2}	1.00E-07	Normal	inf.	$\rho_f \Delta H$	4.38E+01	0.00	0.00
Head Correction : Height difference in reference levels; ΔH (NML-SIRIM)	m	1.15E-03	Rectangular	50	$(\rho_f-\rho_a)g_l$	8.92E+03	10.29	1.03

Note : *ppm = parts per million*

Combined standard uncertainty ($u_{standard}$), u_c (p): 1.6E+02 Pa

Effective degree of freedom, υ: 1.02E+06

3. UNCERTAINTY OF PRESSURE DEVIATION

The model for determining the measurement deviation of the indication of the artefact is as follows:

$$\Delta p = P_{indication} - P_{standard} + \delta_{zero\ deviation} + \delta_{repeatability} \qquad \text{(F1)}$$

where:-

Δp is pressure deviation,

$P_{indication}$ is the indication of the artefact,

$P_{standard}$ is the pressure generated by reference standard,

$\delta_{zero\ deviation}$ is the uncorrected measurement error due to zero error,

$\delta_{repeatability}$ is the measurement error due to repeatability.

The uncertainty estimation of the deviation of the indication of the artefact is calculated separately for measurement values in the direction of increasing pressure and decreasing pressure values. The standard uncertainty has been calculated in accordance with Guideline DKD-R 6-1 Calibration of Pressure Gauges as below:

$$u_{\text{up/down}} = \sqrt{u_{\text{standard}}^2 + u_{\text{indication}}^2 + u_{zerodeviation}^2 + u_{repeatability}^2}$$

where the u_i's are the uncertainties of the various input quantities as specified in function F1.

Uncertainty budget ($u_{up/down}$):

Standard Uncertainty Component	*Source of Uncertainty*	*Value of Standard Uncertainty $u(x_i)$*	*Probability Distribution*	*Sensitivity Coefficient $\lvert c_i \rvert$*	*Uncertainty Contribution $u_i(y) = \lvert c_i \rvert . u(x_i)$*	*Degree of Freedom*
$u_{standard}$	Reference Standard	0.16 kPa	Normal	1	0.16 kPa	1.02E+06
$u_{indication}$	Resolution	0.58 kPa	Rectangular	1	0.58 kPa	∞
$u_{zerodeviation}$	Zero Deviation	0.58 kPa	Rectangular	1	0.58 kPa	∞
$u_{repeatability}$	Repeatability	0.12 kPa	Rectangular	1	0.12 kPa	∞
Combined Standard Uncertainty					0.84 kPa	7.94E+08
Coverage Factor *"k"*					2	
Expanded Uncertainty $U_{up/down}$ (95% of confidence level)					**1.7 kPa**	

Sensitivity Coefficient

The sensitivity coefficient is c_i calculated as the partial derivative of the function (F1) with respect to the quantity x_i

$$c_{P_{indication}} = \frac{\partial \Delta p}{\partial P_{indication}} = 1$$

$$c_{P_{standard}} = \frac{\partial \Delta p}{\partial P_{standard}} = -1$$

$$c_{\delta_{zerodeviation}} = \frac{\partial \Delta p}{\partial \delta_{zerodeviation}} = 1$$

$$c_{\delta_{repeatability}} = \frac{\partial \Delta p}{\partial \delta_{repeatability}} = 1$$

List of the uncertainty components

▪ Resolution

The standard value is 10.0210 MPa at nominal pressure 10 MPa. The resolution corresponds to the digit step. The resolution of the instrument is 0.001 MPa (1 kPa) which is assumed to be a rectangular distribution with a divisor of $\sqrt{3}$, where the limit is assumed to be ± 1 kPa . It is also estimated that the rectangular limit could be out by 0%. Therefore the degree of freedom is $v_1 = (1/2) \text{ x } (100/0)^2 = \infty$. The standard uncertainty is:

$$u_{indication} = 1 / \sqrt{3} = 0.58 \text{ kPa}$$

▪ Reference standard

The standard value is 10.0210 MPa at nominal pressure 10 MPa. According to Table I above, the combined standard uncertainty of pressure generated by the reference standard is:

$$u_{standard} = 0.16 \text{ kPa}$$

▪ Zero deviation

The uncertainty of zero error is determined from the greatest difference among the zero values at the end of the three runs in each measurement cycle. The maximum difference value is 1 kPa , which is assumed to be a rectangular distribution with a divisor of $\sqrt{3}$, where the limit is assumed to be ± 1 kPa. It is also estimated that the rectangular limit could be out by 0%. Therefore the degree of freedom is v_3 = (1/2) x $(100/0)^2 = \infty$. The standard uncertainty is:

$$u_{zerodeviation} = 1 / \sqrt{3} = 0.58 \text{ kPa}$$

▪ Repeatability

The uncertainty of repeatability is determined from the greatest difference among the values measured at the same point. The maximum difference value is 0.4 kPa. A rectangular distribution is assumed with a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 0.2 kPa. It is also estimated that the rectangular limit could be out by 0%. Therefore the degree of freedom is v_4 = (1/2) x $(100/0)^2 = \infty$. The standard uncertainty is:

$$u_{repeatability} = 0.2 / \sqrt{3} = 0.12 \text{ kPa}$$

▪ Combined standard uncertainty of $u_{up/down}$

The degrees of freedom are also combined via the Welch-Satterthwaite formula to give an effective degrees of freedom 7.94E+08. A normal distribution is assumed. The combined standard uncertainty of deviation is calculated from the following equation:-

$$u_{up/down} = \sqrt{\sum u_i^2 \text{ (y)}} = 0.84 \text{ kPa}$$

4. DETERMINATION OF THE EXPANDED UNCERTAINTY

At a 95% confidence level, the expanded uncertainty is directly derived from the combined standard uncertainty by multiplying it by a coverage factor k = 2 :-

$$U_{up/down} = k.\ u_{up/down} = 2 \text{ x } 0.84 \text{ kPa} = \mathbf{1.7} \text{ kPa}$$