25 GDS Helpsheet

GDS INSTRUMENTS LIMITED

World Leaders in Computer Controlled Testing Systems for Geotechnical Engineers and Geologists

Hardware

Triaxial and Consolidation Testing Systems

Pressure Measurement and Control

1. Digital Measurement of Pressure

The GDS triaxial and consolidation testing systems read pressures in a digital or stepped way. The continuous or analogue output of the pressure transducer is digitised into discrete "bits" (both figuratively and literally where a "bit" is a binary digit). This is called "analogue-to-digital conversion" or A/D for short.

For example a 12 bit A/D converter gives a theoretical resolution of 1 in 2 to the power of 12 or 4096 (say 4000). Over 2000 kPa this gives a resolution of 2000/4000 = 0.5 kPa.

Now consider the consequence of measuring the pressure in steps of 0.5 kPa. Take two pressures that are nearly the same say 515.9 kPa and 516.1 kPa. Because the measuring system rounds down it reads these pressures as 515.5 kPa and 516 kPa respectively. In reality the pressures are only 0.2 kPa apart but the system perceives them as being 0.5 kPa apart.

Now consider two pressures which are nearly 1 kPa apart say 515.1 kPa and 515.9 kPa. The measuring system would read these as being 515 kPa and 515.5 kPa respectively. In reality the pressures are 0.8 kPa apart but the system perceives them as being 0.5 kPa apart.

For the example above there is therefore a band of resolution of 0.5 kPa within which the real pressure may wander without the measuring system "seeing" it change.

2. Enhanced Resolution of Pressure Measurement

Electronic noise is one of the main causes of poor resolution of pressure measurement. On some pressure transducers this can be as much as +/-2 bits or about +/-1 kPa on a 2000 kPa range transducer. This noise is usually random. Accordingly the noise can be effectively eliminated by sufficient averaging. In this way resolution can be improved.

This averaging out of noise can be done in firmware (i.e. at the microprocessor level) or in software (i.e. at the controlling computer level). GDS average the readings in firmware. The pressure reading presented to the computer interface is averaged over 32 readings for Mark III controllers set into enhanced precision.

Connecting the controller to a constant pressure of 2000 kPa from a dead weight tester and monitoring the output to the computer gives a variation of about +/-0.25 kPa. This is the real composite system resolution at the computer interface. As you can see it corresponds to the theoretical resolution of the A/D converter. This means that in enhanced precision we have completely eliminated the measuring system noise.

3. Calibration of Transducers

Each transducer has its own calibration relationship between a standardised input and the transducers output. These "signatures" lie within the specification of the transducers linearity, repeatability and zero drift. Nevertheless when different transducers are used to measure the same pressure they will indicate different values. For pressure transducers having combined nonlinearity and hysteresis of +/-0.1% this means that differences of 4 kPa can occur in the 2000 kPa range.

By far the most significant differences arise from temperature related zero drift. Unfortunately this is most difficult to quantify. This is because the transducer manufacturer does not specify exactly how the zeros will drift for any set of transducers. Within their band of specification some may go up while some may go down with different magnitudes of drift at different temperatures. Typically for temperature changes in an office environment a zero shift of +/-2 kPa can be expected for a temperature variation of +/-2°C.

4. Diurnal Variations in Pressure and Volume Change

This random movement with temperature of the zero offset of pressure transducers can affect the conduct of a test. Consider two pressure transducers measuring the same constant pressure. With changing temperature one may indicate an increasing pressure while the other indicates a decrease. Now consider that these two transducers are in pressure controllers which are being used to control constant pressures such as cell and back pressure. As the temperature changes each controller will maintain what it perceives as a constant pressure according to its' transducer. Actually the pressure measurement is changing with temperature and so each controller will impose an actual pressure change while falsely indicating no change in pressure.

This can affect your results in two ways. The first is that your effective stress (cell pressure minus back pressure) will change. This may well be cyclical following the diurnal variation in ambient temperature. You will therefore get additional primary consolidation during one direction of temperature change. This will be followed by swelling during the opposite direction of temperature change. This first effect you cannot influence.

The second effect is that each controller needs to impose a volume change to cause the pressure changes that it is making (inadvertently). This second effect is made worse by working at low pressures. The compressibility of water is 5-10 times higher at 25 kPa than it is at 500 kPa. Avoid low pressures so that these volume changes are kept to an absolute minimum.

Above all you should design your experiment so that these characteristic errors are an insignificant proportion of the parameters you wish to control and measure.

5. Pressure Control

GDS digital pressure/volume controllers exercise control in response to the instantaneous reading of current pressure. This enables the controller to have a rapid response e.g. to follow a moving target.

This instantaneous reading includes the +/- 2 bits of noise i.e. +/- 1 kPa. This means that the pressure seek algorithm built into the firmware must seek to the target pressure to within a dead band of +/- 1 kPa within which the system will not be oscillatory.

6. Avoid Controlling to Small Pressure Differences

Pressure is measured by the system in a digital way. Pressure is controlled to within a proximity band of the target value. In addition each transducer has a unique calibration and set of characteristics. This means there is a band within which the system control of pressure is uncertain. For a controlled hydraulic gradient test this band of uncertainty is made up as follows: 2 kPa (control) + 4 kPa (nonlinearity of transducers) + 4 kPa (zero drift of transducers) = 10 kPa for 2000 kPa range systems i.e. +/-0.25%.

If the system is required to control small pressure differences it is possible that the differential may get "lost" in the band of uncertainty and so the system does not respond. For example setting up a controlled hydraulic gradient using an excess pore pressure of <10 kPa may actually result in a very much lower excess pore pressure or even a reversed gradient. It is good practice therefore to avoid controlling to small pressure differences.

7. What To Do If You Have to Use Small Pressure Differences

Your GDS controllers can effectively exercise control at small pressure differences to +/-1 kPa. You can improve the accuracy of measurement of small differences by checking the controllers before and after a test. Designate one of your controllers as the "master" and then connect it to the other "slave" controllers. On the master set a typical working pressure for your test and observe the readings on the slaves. Do this immediately before and immediately after your test and apply an appropriate correction to the test results.

8. Ranges of Axial Force and Deviator Stress in the GDS Hydraulic Triaxial Cells

There are two GDS low pressure triaxial testing systems for soils based on the Bishop and Wesley-type hydraulic triaxial cells.

There is the 40kN range of axial force system ("four ton system") which is designed to test medium stiff specimens of 100mm diameter. This system also has interchangeable base pedestals and top caps to allow the testing of stiff (70mm diameter) and very stiff (50mm diameter) specimens. The load cell and Digital Transducer Interface (DTI) can be used to make this four ton system into a half ton system by incorporating a 5kN load cell. This allows the system to be used to test soft soils of small diameter.

There is also the 6kN ("half ton system") which is designed to test medium stiff specimens of 38mm diameter. The system also has a 50mm diameter interchangeable base pedestal and top cap to allow the testing of soft soils. There is also a 100mm upgrade to allow the testing of very soft soils.

9. System Resolution

The GDS low pressure (2000 kPa) triaxial testing system is based on the Bishop & Wesley hydraulic triaxial cell. The cell is operated by GDS digital pressure/volume controllers. The statics of the cell are very simple. By considering the equilibrium of the loading ram, the following relationship is obtained :

$$\sigma a = p\ (a / A\ ) + sr\ (1 - a / A\ ) - W / A \qquad (1)$$

Here say is the average axial total stress, sr is the radial total stress or cell pressure, p is the pressure in the lower chamber, A is the current average cross-sectional area of the test specimen (defined as the area of the volumetrically equivalent right cylinder), a is the effective area of the Bellofram Rolling Diaphragm, W is the weight of the loading ram. The computer continuously computes the average axial total stress using equation (1).

The deviator stress is thus:

σa - sr = a / A (p - sr) - W / A (2)

This equation can be adapted to give the resolution of deviator stress Rd as:

Rd = a / A (Rp + Rr) (3)

where Rp and Rr are the resolutions of p and sr respectively.

As can be seen from equation (2) the area ratio a/A controls the amplification or reduction of resolution of axial stress. In GDS cells these a/A ratios are as follows:

Table 1. Area ratios

Diameter of test specimen	38mm	50mm	70mm	100mm
38/50 cell area ratio	2.58	1.49	0.37	
50/70/100 cell area ratio	10.49	5.35	2.62	

As was seen above the resolution of pressure measurement is +/-0.25 kPa while the resolution of pressure control is +/-1 kPa.

It should be noted however that for tests with the lower chamber controller under volume change control the resolution of lower chamber pressure measurement p is still +/-0.25 kPa. This is true of strain control in U-U, C-U, C-D. It is also true of controlled hydraulic gradient and for stress paths mapped to the system resolution.

For tests which are axial strain controlled we have (Rp + Rr) = 1.25. We can now construct a table showing the system resolution of deviator stress. In Table 1 below the resolution of control is given together with the resolution of measurement in parenthesis.

Table 1. Resolution of control (measurement) deviator stress kPa: axial strain controlled tests

Diameter of test specimen	38mm	50mm	70mm	100mm
38/50 cell	+/-3.23(+/-1.29)	+/-1.86(+/-0.75)	+/-0.46(+/-0.19)	
50/70/100 cell	+/-13.11(+/-5.25)	+/-6.69(+/-2.68)	+/-3.28(+/-1.64)	

For tests which are axial stress controlled we have (Rp + Rr) = 2 whence Table 1 can be modified as follows:

Table 2. Resolution of control (measurement) deviator stress kPa: axial stress controlled tests

Diameter of test specimen	38mm	50mm	70mm	100mm
38/50 cell	+/-5.16(+/-1.29)	+/-2.98(+/-0.75)		+/-0.74(+/-0.19)

50/70/100 cell	+/-20.98(+/-5.25)	+/-10.70(+/-2.68)+/-5.24(+/-1.64)

10. Conclusions

From the foregoing the following general principles can be seen to be advisable:

1. Avoid small pressure differences. If you have to use small pressure differences calibrate your controllers against a designated master controller before and after each test.

2. Avoid low pressures. The compressibility of water is 5-10 times higher at 25 kPa than it is at 500 kPa.

3. Design your experiment so that the inevitable characteristic errors discussed above are an insignificant proportion of the parameters you wish to control and measure.

4. Wherever possible choose strain controlled tests.

5. When testing soft soils use the largest size possible in the smallest cell possible. For example use 50mm diameter test specimens in the 38/50 cell. For very low pressure work use the 100mm upgrade for the 38/50 cell.

6. In the 50/70/100 cell use 50 and 70mm diameter test specimens for stiff (70mm dia.) and very stiff (50mm dia) soils only.