

PROCEDURE FOR

MEASURING THE MODULUS OF ELASTICITY OF CONCRETE CORES AND CYLINDERS

1. PROCEDURE OVERVIEW

The determination of the modulus of elasticity for cylindrical concrete samples such as molded cylinders and drilled cores is outlined in this procedure. After preparing the ends and installing a compressometer, a series of compressive stress cycles up to approximately 40 percent of the measured compressive strength will be applied. The modulus of elasticity of the concrete will correspond to the average slope of the stress-strain responses captured during cyclic loading. ASTM C469 (Ref. 7.1) and ASTM C42 (Ref. 7.2) formed the basis for the development of this procedure.

Detailed instructions for operating the FX-250T test machine are provided in Appendix A and detailed instructions for operating the FX-500 test machine are provided in Appendix B. The instructions provided in this procedure, along with Appendices A and B, can be used to determine the complete load vs. axial shortening of a sample provided that all displacement sensors are removed from the sample shortly after the maximum load has been reached. Failure to remove the sensors could result in severe damage if the concrete sample is crushed excessively.

1.1. Student Responsibilities:

- Read and understand the requirements of this procedure
- Provide concrete samples for testing
- Clean testing machine after use

1.2. Staff Responsibilities:

- Read and understand the requirements of this procedure
- Assist students with testing as needed

2. EQUIPMENT AND TOOLS

- Diamond End Grinding Machine
- Compression Testing Machine
- Assorted Test Fixtures
- Pi Tape
- Calipers
- Ruler
- Camera
- Compressometer

3. MATERIALS

- Concrete Samples (Cores, Cylinders, or Both)

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4. PERSONAL PROTECTIVE EQUIPMENT

- Safety glasses
- Safety shoes
- Dust Mask
- Gloves

5. DETAILED PROCEDURE

- 5.1. Use a minimum of two companion samples to determine the concrete compressive strength at the time of testing (f_c).

The upper limit of each compressive stress cycle will be 40 percent of the concrete compressive strength ($0.4f_c$) measured immediately in advance of the modulus of elasticity testing. The compressive strength should be determined in accordance with the appropriate FSEL standard procedure.

- 5.2. Verify that the compression-testing machine is in working order and that it has been calibrated per FSEL operating procedure.

The compression-testing machine(s) should be calibrated on an annual basis. It should also be noted that calibration of these machines is limited to 100,000 lb of compressive force due to the size of the compressive machine and the size of the calibration load cells available at FSEL.

- 5.3. Prepare concrete samples for modulus of elasticity testing.

- 5.3.1. Verify that the concrete samples do not have any significant defects that may affect the quality of the test results.

- 5.3.2. Use a diamond end grinding machine as necessary to square off and flatten each of the sample ends to meet the tolerances of ASTM C39 (Ref. 7.3).

Diamond end grinding of the sample ends may be completed well in advance (e.g. upon demolding) of compression testing. Information about grinding cylinder and core ends can be found in the FSEL Procedure For Grinding the Ends of Concrete Cylinders and Cores.

Sulfur mortar caps prepared in accordance with ASTM C617 (Ref. 7.4) are a suitable alternative to the use of an end grinding machine. The sample length must be recorded prior to preparing the sulfur caps.

- 5.3.3. Use calipers or a ruler to measure the sample length (L) according to the guidance of ASTM C1542 (Ref. 7.5).

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5.3.4. Use a pi tape to measure the sample diameter (D) and subsequently calculate the length-to-diameter ratio (L/D) and cross-sectional area (A).

5.3.5. If the length-to-diameter ratio (L/D) exceeds 2.1, shorten the sample through further grinding until the sample length is between 1.9 and 2.1 times the diameter.

An L/D less than 1.9 and greater than 1.5 is acceptable, but not desirable.

5.3.6. Record the sample identifier, final sample length (to the nearest 0.1 inches), sample diameter (to the nearest 0.01 inches), length-to-diameter ratio, and cross-sectional area.

5.4. Prepare the compression-testing machine.

5.4.1. Install bearing blocks and other test fixtures as necessary to successfully complete modulus of elasticity testing of the samples.

5.4.2. Connect the compression-testing machine to the indicator or data acquisition system.

Detailed instructions for operating the FX-250T test machine are provided in Appendix A. This step is not needed if using the FX-500 test machine.

5.4.3. Turn on the compression-testing machine and allow the electronic and hydraulic systems to equalize for a minimum of 15 minutes.

Equalization of the electrical and hydraulic systems is necessary to ensure stable readings and repeatable results. Detailed instructions for operating the FX-250T and FX-500 test machines are provided in Appendices A and B respectively.

5.5. Verify that the compressometer is in working order and that any displacement transducers have been calibrated per FSEL operating procedures.

Calibration of the displacement transducers should be completed on an annual. Measurement of the sample deformation may also be accomplished using an integral dial gauge.

5.6. Allow the compressometer and indicator or data acquisition system to equalize near the testing machine.

5.6.1. Place the compressometer near the testing machine.

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5.6.2. Connect the displacement transducer(s) to the indicator or data acquisition system and provide power as appropriate.

5.6.3. Allow the compressometer and indicator or data acquisition system to equalize in the testing environment for a minimum of 15 minutes.

5.7. Setup each sample for modulus of elasticity testing in the compression-testing machine.

Test each concrete sample as soon as practicable after removal from its previous state of conditioning.

5.7.1. Wipe the concrete sample as necessary to remove any surface moisture.

5.7.2. Mount the compressometer at the mid-height of the concrete sample and remove the control rods from the upper and lower yokes.

Detailed instructions for operating the FX-250T and FX-500 test machines are provided in Appendices A and B respectively.

5.7.3. Ensure the displacement measuring instrument is aligned with the bearing surface and has the proper effective stroke.

Detailed instructions for operating the FX-250T and FX-500 test machines are provided in Appendices A and B respectively.

5.7.4. Note the gage length (L) of the compressometer.

5.7.5. Wipe clean the bearing faces of the upper and lower bearing blocks and place the sample, with the compressometer rigidly attached, on the lower bearing block.

5.7.6. Using the concentric circles on the bearing blocks as a point of reference, carefully align the axis of the sample with the spherically seated (upper) block.

5.7.7. Remove the control rods from the extensometer.

The control rods hold the compressometer assembly stable while installing it on the concrete sample. These rods must be removed prior to testing of the compressometer will not be able to deform with the sample. Failure to remove the control rods could result in damage to the compressometer.

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Detailed instructions for operating the FX-250T and FX-500 test machines are provided in Appendices A and B respectively.

- 5.7.8. Tilt the spherically seated block so that the bearing face is parallel to the top surface of the sample.
- 5.7.9. Zero the readouts or indicators of both the compression-testing machine and compressometer as appropriate.

Detailed instructions for operating the FX-250T test machine are provided in Appendix A. This step is not needed if using the FX-500 test machine.

- 5.8. Verify the function of the compressometer during a single loading cycle, make adjustments and repeat as necessary to ensure accurate measurement of the modulus of elasticity.

The initial loading cycle is intended to seat the sample in the test fixtures and check for any errors such a slip in the compressometer. Observe the test data during this loading cycle but it should not be used for calculations of modulus of elasticity.

Detailed instructions for operating the FX-250T and FX-500 test machines are provided in Appendices A and B respectively.

- 5.8.1. Starting near zero, apply load at a continuous rate of movement corresponding to a stress rate of 35 ± 7 psi per second; refer to corresponding load rates in Table 1.

Table 1 – Rate of Loading

Sample Diameter	Stress Rate	Load Rate
3 in.	35 ± 7 psi/s	250 ± 50 lbs./s
4 in.		440 ± 90 lbs./s
6 in.		990 ± 200 lbs./s

- 5.8.2. Upon reaching 40 percent of the measured compressive strength ($0.4f_c$), reduce the load to near zero at the same rate at which it was applied.
- 5.8.3. Observe the performance of the compressometer during the cycle and correct any unusual behavior as necessary.

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- 5.9. Complete a minimum of two additional loading cycles (as outlined in Articles 5.8.1 and 5.8.2) to record the linear-elastic response of each concrete sample.

With the observation cycle completed per Article 5.8, the two cycles required per this article are for data collection and calculation of modulus of elasticity. However, these cycles should be performed in the same manner as the observation, or first, cycle.

Do not interrupt the loading for the purposes of obtaining the measurements outlined below. If the observer fails to obtain a reading, complete the cycle, document it, and repeat it.

- 5.9.1. During each cycle, record the applied load and deformation when the longitudinal strain is approximately 0.000050; refer to the corresponding compressometer deformation in Table 2.

Table 2 – Compressometer Deformation at a strain of 0.000050

Sample Diameter	Gage Length	Deformation
3 in.	5.5 in.	0.00055 in.
4 in.		
6 in.	8 in.	0.00080 in.

- 5.9.2. During each cycle, record the applied load and compressometer deformation when the compressive stress is approximately 40 percent of the measured compressive strength ($0.4f_c$).

- 5.9.3. Record each cycle and the corresponding load-deformation measurements.

Data can be recorded by hand or exported from the test machine. Detailed instructions for operating the FX-250T and FX-500 test machines are provided in Appendices A and B respectively.

- 5.10. Calculate the modulus of elasticity of each sample (E_c).

Detailed instructions for operating the FX-250T and FX-500 test machines are provided in Appendices A and B respectively.

- 5.10.1. Calculate the compressive stresses (σ) applied during each cycle by dividing the measured loads by the cross-sectional area.

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- 5.10.2. Calculate the longitudinal strains (ε) on the basis of the deformations measured during each cycle.

$$\varepsilon = \delta/2L$$

Where: δ = deformation indicated by compressometer.

The lever arm of a typical compressometer effectively doubles the axial deformation of the sample; the indicated deformation must therefore be divided by 2.

- 5.10.3. Use the calculated stresses and strains to determine the slope of each cycle (E).

$$E = (\sigma_2 - \sigma_1)/(\varepsilon_2 - \varepsilon_1)$$

Where: σ_1 = stress corresponding to ε_1

σ_2 = actual stress at stress of approximately $0.4f_c$

ε_1 = actual strain at strain of approximately 0.000050

ε_2 = strain corresponding to stress σ_2

- 5.10.4. Calculate the modulus of elasticity of each sample (E_c) by averaging the two values obtained per the calculations in Article 5.10.3.

Outlying results may be omitted from the calculation as deemed appropriate by FSEL project personnel.

- 5.10.5. Record the modulus of elasticity of each sample to the nearest 10 ksi.

- 5.11. Discard the tested cylinder in the hopper located in the concrete testing room.

If the hopper is full or nearly full, notify FSEL technical staff so that the hopper can be emptied.

- 5.12. Clean all concrete dust and debris from the test machine and surrounding area.

- 5.13. Turn off the test machine.

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6. SUPPORTING DOCUMENTS

None.

7. REFERENCED DOCUMENTS

- 7.1. ASTM C469-10: Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. West Conshohocken: ASTM International, 2010.
- 7.2. ASTM C42-12: Obtaining and Testing Drilled Cores and Sawed Beams of Concrete. West Conshohocken: ASTM International, 2012.
- 7.3. ASTM C39-12: *Compressive Strength of Cylindrical Concrete Specimens*. West Conshohocken: ASTM International, 2012.
- 7.4. ASTM C617-11: *Capping Cylindrical Concrete Specimens*. West Conshohocken: ASTM International, 2011.
- 7.5. ASTM C1542-02: *Measuring Length of Concrete Cores*. West Conshohocken: ASTM International, 2002.

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8. RECORD OF REVISIONS

Revision	Date	Affected Pages	Description
0	2016-10-21	All	Initial Issue

MEASURING THE MODULUS OF ELASTICITY OF CONCRETE CORES AND CYLINDERS

A. INSTRUCTIONS FOR USE OF FX-250T TEST MACHINE

Setup for elastic modulus testing with the FX-250T machine depends on whether the user intends to record discrete data points for calculation or continuously record stress-strain data.

5.4.2 *An external data acquisition system and a compressometer with DAQ-compatible displacement transducers are required. All measurement devices must be connected to a pod located next to the testing machine, which in turn must be connected to the data acquisition system. Connect the gray cable attached to the test machine pressure transducer to the red cable secured in Channel 2. Connect displacement transducers to Channels 3, 4, or both using full bridge connections (see additional details below). To turn on the test machine, toggle the power switch below the load control valves.*

5.4.3 *Supply power to the data acquisition system and turn on the computer and data scanner. Open the program entitled "AGIDAQ-Compressometer.vi" in LabVIEW. Run the program. Under the "Setup" tab, click on "Change Setup." Click on "Load Setup" and select the file "Compressometer" within the UserData/Compressometer folder. Click "OK." The program will prompt the user to save three files (.RAW, .ENG, .LOG) on the hard drive. The "Setup" tab should update with the measurement device information. Ensure that the descriptions of the displacement transducers and channel numbers match the physical setup.*

5.7.2 *Mount the compressometer to the test specimen.*

The recommended compressometer consists of two separate fixtures mounted on the upper and lower halves of a 4 in. x 8 in. concrete cylinder or core at a set distance apart. The upper yoke consists of two rigidly connected aluminum rings mounted to the cylinder with a set of four pins at the upper ring. The lower yoke consists of a single aluminum ring also mounted to the cylinder with a set of four pins. Prior to mounting, the two yokes are loosely separated at a fixed gage length of 5.25 in. between mounting rings with a pair of control rods on opposite sides. Two PVC spacers are temporarily placed on opposite sides between the lower yoke and the lower ring of the upper yoke ensure that the yokes lie in parallel. Two displacement transducers are clamped to the lower ring of the upper yoke. The shaft of each transducer should be aligned with the underside of the lower ring of the upper yoke. The pin from each transducer will bear on the lower yoke with adequate stroke to complete testing.

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Sample placement should be done with great care to ensure it is centered both vertically and laterally within the extensometer. The yokes of the extensometer must be parallel with each other and with the ends of the specimen.

- 5.7.3 *The displacement transducers must be properly positioned prior to testing. To accomplish this, gently insert the metal spacer between the displacement transducer tip and the metal surface that it contacts. The spacer should fit within the space and the transducer tip should contact the metal surface below when the spacer is removed.*
- 5.7.7 *Remove the control rods and PVC spacers from the compressometer and check that the specimen is centered in the test machine.*
- 5.7.9 *Click the "Tare" button and choose "Zero All Channels" within the data acquisition software.*
- 5.8 Click on "Monitor" within the "Run Options" panel on the left. Check that the displacement transducers are reading correctly by slightly depressing each transducer while checking that the raw data under the "Data" tab changes.

Change any scan and display options as needed/desired. Under the "Run Options" panel on the left, choose an adequate scan delay time (0.5 sec is recommended). The scanner records loads and displacements. Stresses and strains are computed and displayed in the "E-Nu Test Data" tab. Input the specimen diameter and compressometer gage length. A computed moving average of a set number of data points can be displayed if desired (otherwise choose a value of 1).

Click on "Tare" within the "Run Options" panel to tare data and begin recording data continuously.

Loading is controlled with a four-way load-type control valve and load rate control valve on the test machine. When not loading or positioning the test table, the load-type valve should be in the "Hold" position. Other valve positions include "Retract" which will lower the testing table, "Full Advance" which will quickly raise the test table at a fixed rate, and "Metered Advance" which will raise the test table at a rate controlled using the rate control valve. The advance rate is increased by rotating the rate control valve counterclockwise.

To begin the test, raise the testing table until the top of the cylinder or core is less than 1/8 in. from the upper test platen. Confirm that the test specimen is centered beneath the upper platen. With the load-type valve in the "Metered Advance" position, use the rate control valve

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to load the specimen at 35 ± 7 psi/s. The current load rate will be displayed on the computer with the stress-strain data. Upon reaching 40 percent of f_c , turn the load-type valve to the "Hold" position to stop loading and then to the "Retract" position to unload the specimen.

5.9.3 Test data is recorded in the .ENG file saved with LabVIEW. The data file contains recorded loads and displacements. Stresses and strains can be obtained by dividing the loads by measured areas and displacements by the compressometer gage length.

5.10 The FX-250 machine does not perform any calculations related to the modulus of elasticity. All calculations should be performed per the provisions of Article 5.10.

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B. INSTRUCTIONS FOR USE OF FX-500 TEST MACHINE

- 5.4.3 *To turn on the FX-500 machine use the toggle switch near the lower left corner of the display. The display should power on and the onboard computer should start.*

Log in to the machine using your User ID and PIN. After logging into the machine, check and update the user information as needed. When the information is completed, click "Done."

- 5.7.2 *The recommended compressometer consists of two separate fixtures mounted on the upper and lower halves of a 4 in. x 8 in. concrete cylinder or core at a set distance apart. The upper yoke consists of a rigid yoke that attaches to the sample with two setscrews. The lower yoke consists of a rigid yoke that attached to the sample with three setscrews. Prior to mounting, the two yokes are loosely separated at a fixed gage length of 5.25 in. between mounting rings with a pair of control rods on opposite sides.*

Sample placement should be done with great care to ensure it is centered both vertically and laterally with in the extensometer. The yokes of the extensometer must be parallel with each other and with the ends of the specimen.

- 5.7.3 *The FX-500 machine used an LVDT with a stroke of 0.05 in. the LVDT can be adjusted by loosening that thumbscrew on the attachment housing. The LVDT should be aligned vertically with the bearing surface attached to the lower ring of the modulus of elasticity cage.*

The LVDT must be properly positioned prior to testing. To accomplish this, gently insert the metal spacer between the LVDT housing and the annular bearing block attached to the LVDT plunger. Next, lower the LVDT along its connecting rod until the plunger contacts the bearing surface. Once the plunger contacts the bearing surface (with the spacer inserted) tighten the thumbscrew to lock the LVDT in place and remove the metal spacer. Check the LVDT's range of motion by gently displacing the plunger by hand. Ensure the plunger returns to contact with the bearing surface after displacement.

- 5.7.7 *Remove the control rods from the compressometer and check that the specimen is centered in the test machine.*

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- 5.8 Select “MOE” for the dropdown menu at the upper right corner of the screen. Confirm the data displayed on the right side of the screen. It is recommended that the nominal diameter and height of the specimen be entered rather than those measured per this procedure. The load rate, or “ramp” should be 35 psi/s per the ASTM C469 (Ref 7.1). The default preload is set 250 lb. The gage length should be consistent with the size of the sample being tested (5.5 in. for a 3 or 4 in. diameter specimen; 8 in. for a 6 in. diameter specimen). The “Comp. Brk” value should be average breaking strength (in lb) of two companion samples.

To begin the test, click and hold “Jog Advance” to raise the testing table. Hold “Jog Advance” until the top of the cylinder or core is less than 1/8 in. from the upper test platen. Click the “Start Test” button to begin the modulus of elasticity test. The test machine will automatically apply the specified preload then begin applying load at the rate specified in Article 5.8.1. After the test is complete click and hold “Jog Retract” to reset the test machine for the next sample.

The FX-500 machine will automatically conduct the two loading cycles required by Ref. 7.1.

- 5.9.3 *To export the data, click on the “Data/Reports” button in the lower right corner of the screen. Select “Move test data to USB flash drive” and choose the appropriate date range. Click the “Generate Report/Transfer” button to complete the export to the USB flash drive. Please return the USB flash drive to the FX-500 machine after transferring the data.*

The data file will contain columns of data for time, load (in lbf.), stress (in psi), and strain. Identify the rows of data that are needed for calculations as described in Article 5.10.3. Note that the “stress” data are based on the specimen diameter entered into the test machine. Stress should be based on the diameter determined in Article 5.3.4. Recalculate stress(es) if necessary.

- 5.10 The FX-500 machine will automatically calculate and display a modulus of elasticity value based on the recorded data. Through experience, FSEL personnel have observed that the automatically calculated value can differ slightly from values calculated by hand using the data recorded during the test. Thus, it is recommended that the modulus of elasticity be calculated by the user after exporting the data from the test.