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NASA TECHNICAL MEMORANDUM

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RELATIVE STIFFNESS OF FLAT CONDUCTOR CABLES

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By James D. Hankins
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The measurement of the bending moment required to obtain a given deflection in short lengths of flat conductor cable (FCC) is presented in this report.

Experimental data were taken on 10 different samples of FCC and normalized to express all bending moments (relative stiffness factor) in terms of a cable 5.1 cm (2.0 in.) in width.

Data are presented in tabular and graphical form for the convenience of designers who may be interested in finding torques exerted on critical components by short lengths of FCC.

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NASA TECHNICAL MEMORANDUM X-73304

RELATIVE STIFFNESS OF FLAT CONDUCTOR CABLES

SUMMARY

The measurement of the bending moment required to obtain a given deflection in short lengths of flat conductor cable (FCC) is presented in this report.

Experimental data were taken on 10 different samples of FCC and normalized to express all bending moments (relative stiffness factor) in terms of a cable 5.1 cm (2.0 in.) in width.

Data are presented in graphical form for the convenience of designers who may be interested in finding the torques exerted on critical components by short lengths of FCC.

INTRODUCTION

The bending moment required to cause deflections in FCC is of importance in many areas of application. A prime example is the relatively low force-moment that the cable applies to the gimbals of the Apollo Telescope Mount. In applications such as this, a proper selection from the available types of FCC can optimize the effects of the bending moment characteristic. Incidentally, FCC was selected (mandatory) over round wire because of its much lower resistance to bending.

The purpose of this study was to develop a simple method for measuring the bending moment of FCC and to measure the bending moment (relative stiffness factor) of various FCC specimens. Although many configurations of FCC are available, this study was limited to 10 samples. Table 1 lists the nominal physical characteristics and the resulting relative stiffness data of the selected specimens (Fig. 1).

EXPERIMENTAL PROCEDURE AND EQUIPMENT

Perhaps the simplest concept for describing relative stiffness in FCC would be to consider the sample as a cantilever beam; thus, any force causing a deflection of the free end from its position of equilibrium would cause the beam to exert an equal and oppositely directed reactive force because of material elasticity. Cable stiffness then could be measured in terms of this reactive force — the greater the reactive force (for any given deflection), the greater the stiffness.

Simple beam theory shows that when a cantilever beam is subjected to a concentrated load at its free end, the fibers on one side elongate, while the fibers on the opposite side shorten; this causes the beam to deflect and take the form of a curve. For this case, the deflection of the free end of the beam is given by the following expression:

$$\text{deflection} = \frac{FL^3}{3EI} \quad , \tag{1}$$

where

F = applied force (lb)

L = length of moment arm (in.)

E = modulus of elasticity (lb/in.^{3})

I = moment of inertia of rectangular beam (in.^{4})
(= 1/12 × beam width × beam thickness^3).

Based on this relation, it is entirely possible to perform a simple, controlled experiment and determine E for a given FCC specimen. For this situation, E would be a composite modulus of elasticity representing the combined elastic effect of all material elements within the cross section of the FCC. However, equation (1) actually has limited usefulness for our purposes since in applying it one must be very careful to remain within the limitations imposed by the assumptions listed below:

1. Stresses caused by bending must remain below the proportional limit. (Hooke's Law applies.)

2. A plane section across the beam must remain a plane after bending.

3. The length of the elastic curve is the same as the length of its horizontal projection, i.e., very small angular deflections.

4. Deflections caused by shear are negligible.

Since, in making all desired measurements on FCC, it would be impossible to adhere to these restrictive assumptions, it became necessary to define another technique for describing relative stiffness. The method decided upon is, in reality, a version of the cantilever technique described above and involves nothing more than custom measuring the deflection produced by measurable forces at various moment arms of interest.

The test setup for measuring these bending moments is shown in schematic form in Figure 2; a photograph of a typical test setup is shown in Figure 3; and an illustration of the bridle assembly is shown in Figure 4.

Before the bending moment tests were started, each of the force gauges was calibrated to determine the amount of linear movement of the tip of the force arm for a given change in the force reading.

In the bending moment test, the force gauge was clamped to the face of a compound table; a bridle assembly was then connected between the cable and the tip of the force gauge.

The compound table was one in which the work surface could be moved along two mutually perpendicular axes by micrometer adjusting screws. The bridle assembly consisted of a thin aluminum strip slightly longer than the width of the test cables. A small hole was drilled in each end of the strip, and a thin string was used to connect the strip to the tip of the force gauge.

The micrometer adjustment on the compound table was changed in increments of 2.54 mm, thus causing the force gauge to move away from the cable. For each increment that the table was moved, the force gauge was read and the net displacement of the FCC was calculated by taking the displacement of the table and subtracting from it the displacement of the tip of the force gauge with respect to the table.

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By using the procedure described above, the deflection of the FCC is measured along a direction which at all times was perpendicular to the original neutral axis of the FCC (cable in the unstressed state).

TEST RESULTS AND DISCUSSION

Each of the 10 cable samples was tested as described by the preceeding procedure. Figures 5 through 14 are plots of the force versus deflection data taken for each cable sample.* The magnitude of the applied force was normalized in all cases to that which could be expected for a cable of 5.1-cm (2.0-in.) width.

It will be noted that the slope of the curves in Figures 5 through 14 increases as the deflection increases. The principal reason for this is believed to be the fact that the effective moment arm length decreases as the deflection increases (nonconformity to assumption 3); for small deflections, this effect can be neglected.

Comparative information can be obtained from Figures 5 through 14 if a relative stiffness factor is defined as the ratio of the applied force (at a particular moment arm) to a deflection equal to 10 percent of the length of the moment arm. (NOTE: The 10 percent multiplier is arbitrary and was chosen only to cause the relative stiffness factor to be computed at small angular deflections of the FCC.)

The relative stiffness factor, as defined, has the units of a spring constant but should not be confused with or equated to the spring constant for a linear spring. The relative stiffness factor, as defined, is a nonlinear function of the moment arm length. As the moment arm length decreases, the relative stiffness factor increases. Therefore, it is possible to calculate a relative stiffness factor for each moment arm length for each cable sample. Table 1 gives these factors for each cable sample in tabular form, and Figure 15 depicts the same data in graphical form. These curves give an excellent indication of the relative stiffness factor for moment arm lenghts in the approximate range from 3.8 cm (1.5 in.) to 7.6 cm (3.0 in.).

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* Cross-section dimensions shown in each figure were measured in the laboratory with a Unitron Metallograph. Optical magnification powers of 50 and 100 were used.

TABLE 1. PHYSICAL AND RELATIVE STIFFNESS DATA FOR SAMPLE CABLES

Cable Sample No.	Cable Width (mm)	Type of Insulation	Nominal Size of Conductors (mm)	Number of Conductors	Type of Shield	Relative Stiffness Factor[a] (gm/mm)			Relative Stiffness Ratio[b]		
						7.6-cm Moment Arm	5.1-cm Moment Arm	3.8-cm Moment Arm	7.6-cm Moment Arm	5.1-cm Moment Arm	3.8-cm Moment Arm
1	50.8 (2.0 in.)	Polyimide (Kapton)	0.10 × 1.0 (0.004 × 0.040 in.)	25	Copper Screen (Double)	2.1	4.9	7.4	26	27	27
2	50.8 (2.0 in.)	Polyimide (Kapton)	0.10 × 1.0 (0.004 × 0.040 in.)	25	Copper Foil (Double)	1.4	2.5	3.4	18	14	13
3	50.8 (2.0 in.)	Polyester (Mylar)	0.05 × 0.64 (0.002 × 0.025 in.)	25	Copper Foil (Single)	0.15	0.27	0.37	1.9	1.5	1.4
4	50.8 (2.0 in.)	Polyimide (Kapton)	0.10 × 1.0 (0.004 × 0.040 in.)	25	None	0.40	1.0	1.3	5	5.5	5
5	50.8 (2.0 in.)	Polyester (Mylar)	0.05 × 0.64 (0.002 × 0.025 in.)	25	None	0.12	0.24	0.35	1.5	1.3	1.3
6	63.5 (2.5 in.)	Fluoro-carbon (TFE)	0.08 × 1.3 (0.003 × 0.050 in.)	32	None	0.060	0.18	0.27	1	1	1
7	47.5 (2.0 in.)	Polyimide (Kapton)	0.13 × 3.18 (0.005 × 0.125 in.)	10	None	0.58	1.30	1.76	7	7	7
8	63.5 (2.5 in.)	Polyimide (Kapton)	0.08 × 6.35 (0.003 × 0.250 in.)	8	None	0.22	0.55	1.0	2.7	3	3.7
9	48.3 (2.0 in.)	Polyimide (Kapton)	0.20 × 22.0 (0.010 × 0.865 in.)	2	None	3.0	6.9	9.2	37	38	34
10	63.5 (2.5 in.)	Polyimide (Kapton)	0.08 × 1.3 (0.003 × 0.050 in.)	32	None	0.3	0.6	1.1	3.7	3.5	4

NOTE: All relative stiffness data are normalized with respect to 5.1-cm (2.0-in.) wide cables. Figure 14 gives the graphic portrayal of relative stiffness factors, and Figure 1 gives the typical construction of shielded FCC. Nonshielded FCC is similarly constructed, but without the shielding material.

a. Relative stiffness factor $= \dfrac{\text{applied force (at selected moment arm)}}{\text{deflection (equal to 10 percent of moment arm)}}$

b. Relative stiffness ratio $= \dfrac{\text{relative stiffness factor (cable of interest)}}{\text{relative stiffness factor (reference Cable No. 6)}}$

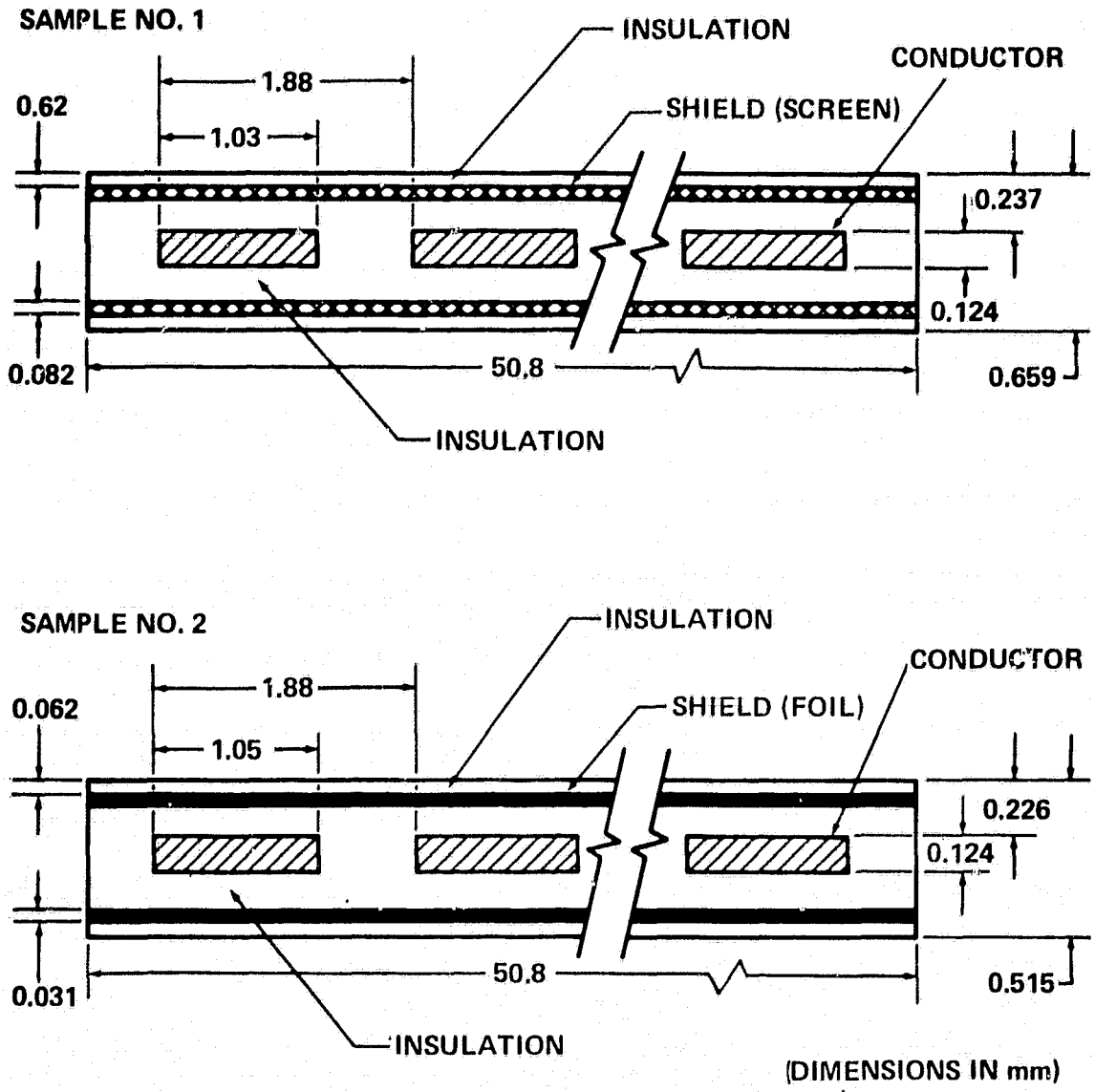

Figure 1. Typical construction of shielded FCC.

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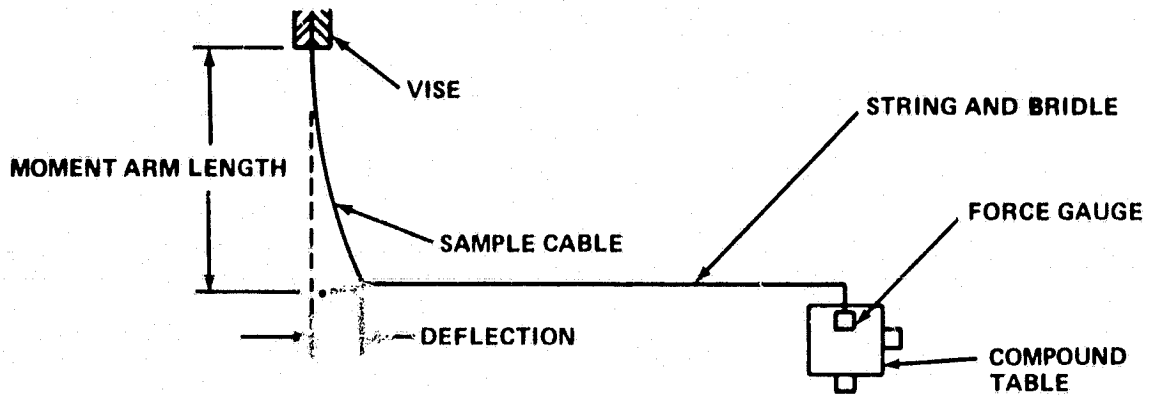

Figure 2. Schematic of typical test setup.

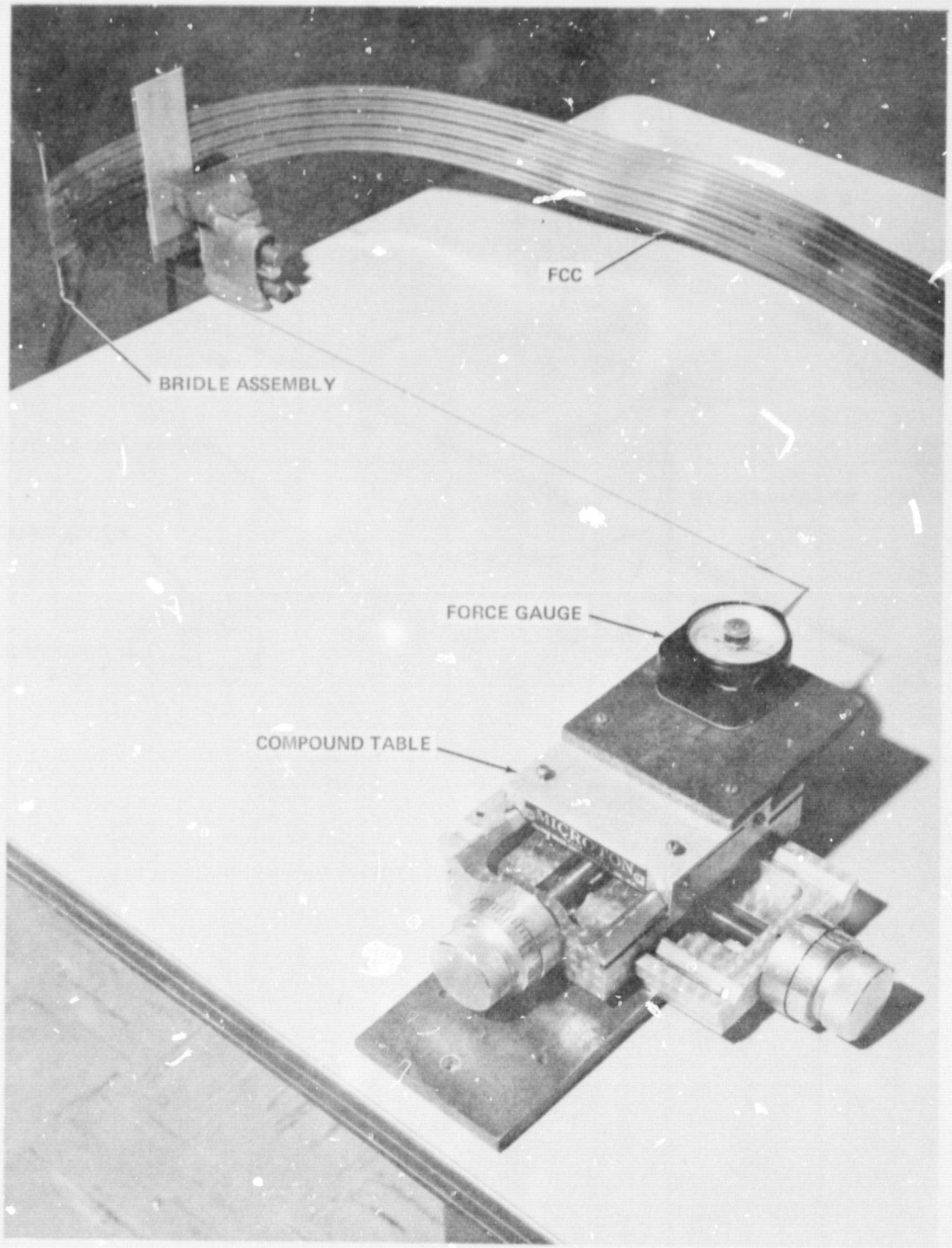

Figure 3. Photograph of typical test setup.

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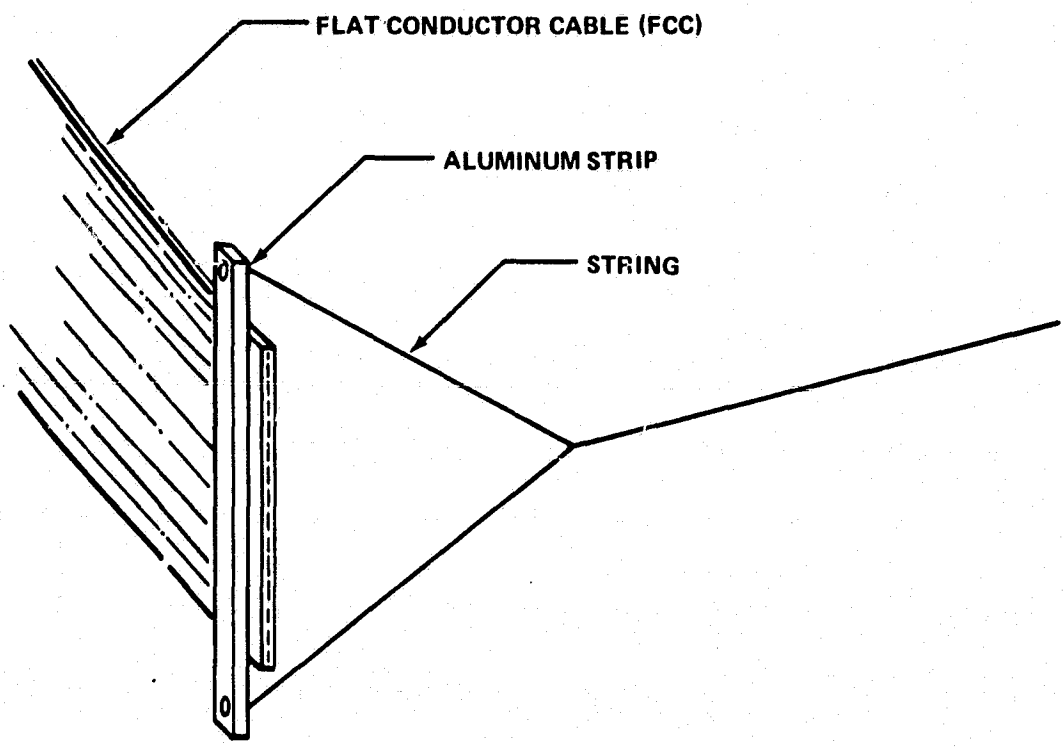

Figure 4. Bridle assembly.

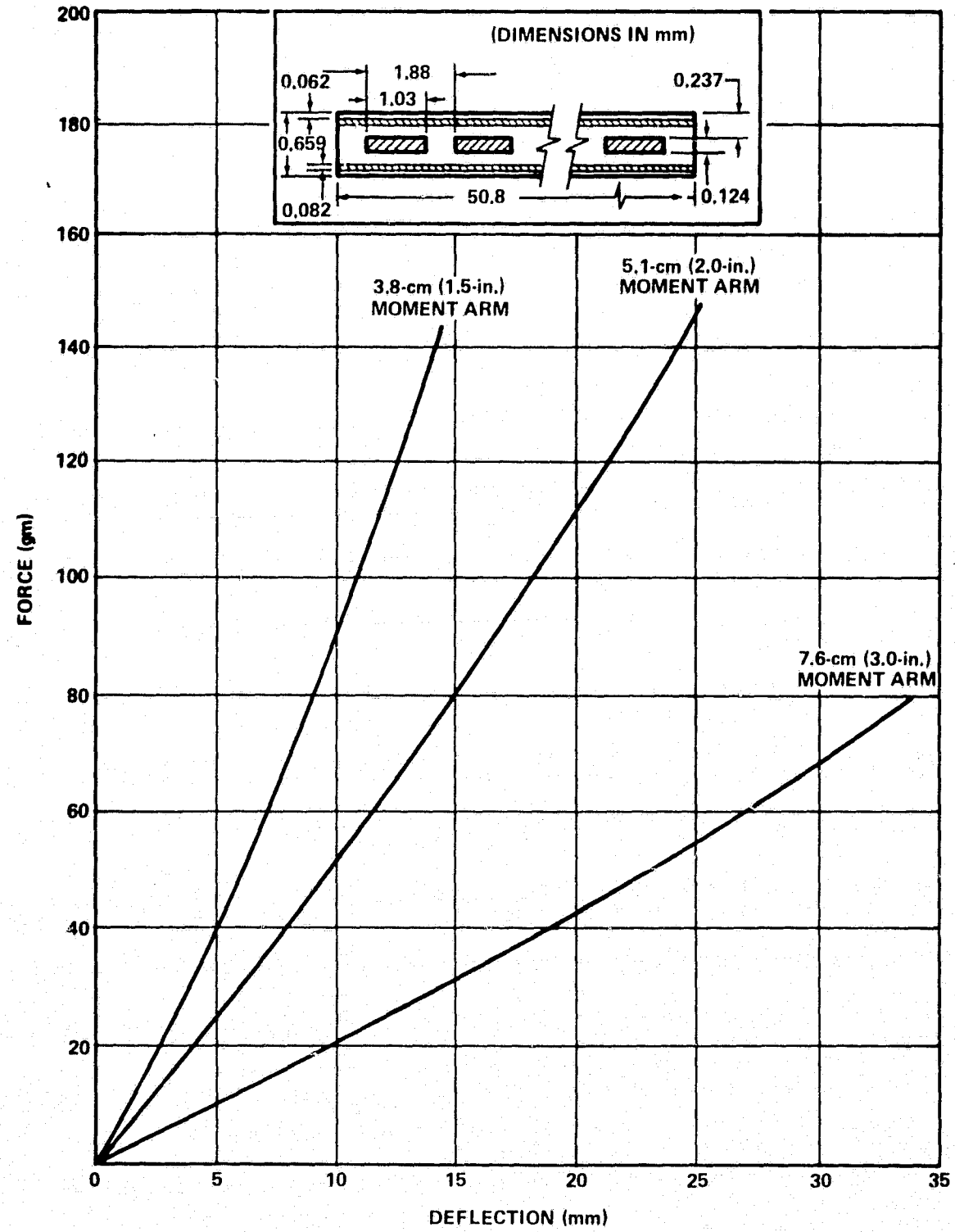

Figure 5. Force versus deflection characteristic for FCC sample No. 1.

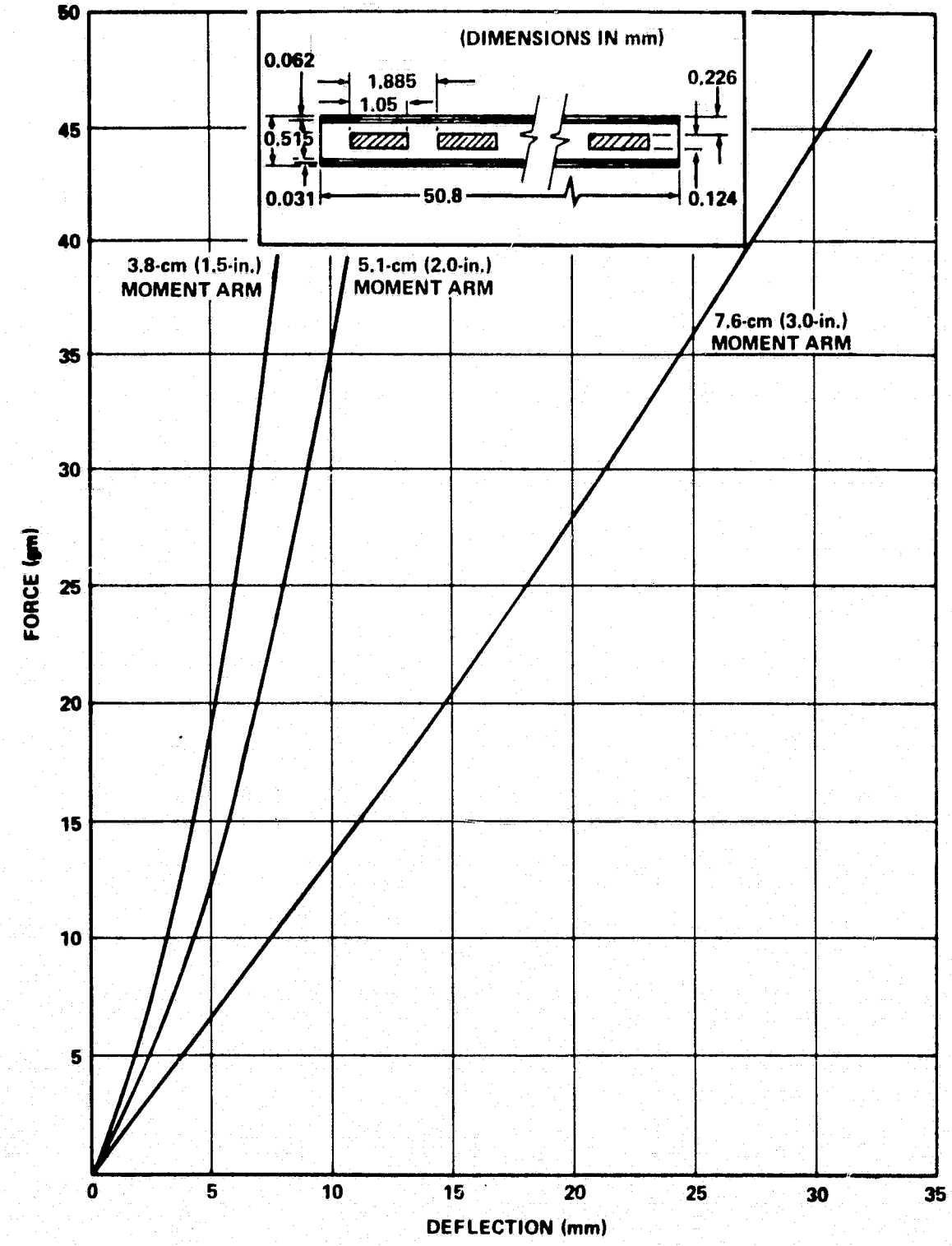

Figure 6. Force versus deflection characteristic for FCC sample No. 2.

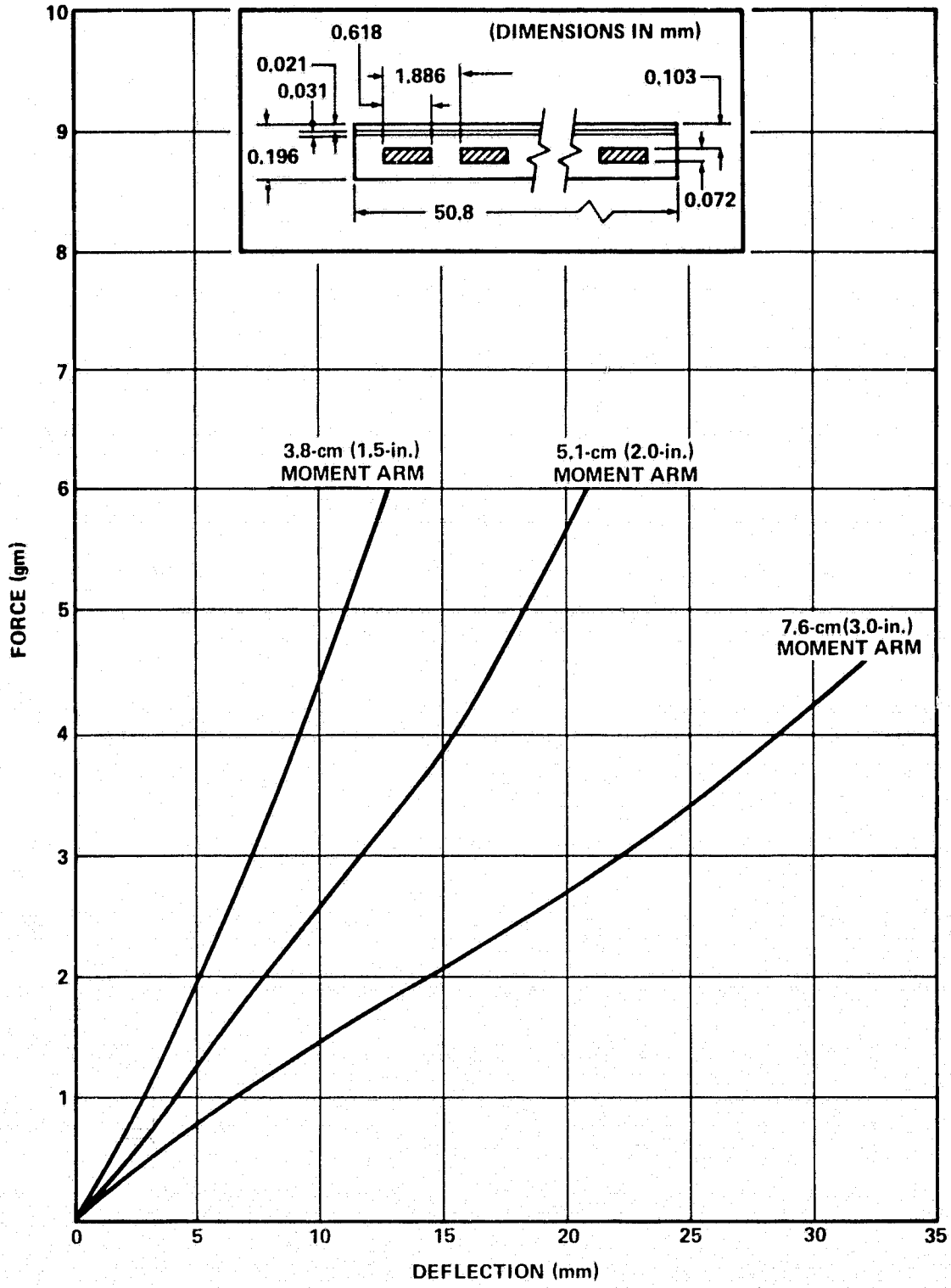

Figure 7. Force versus deflection characteristic for FCC sample No. 3.

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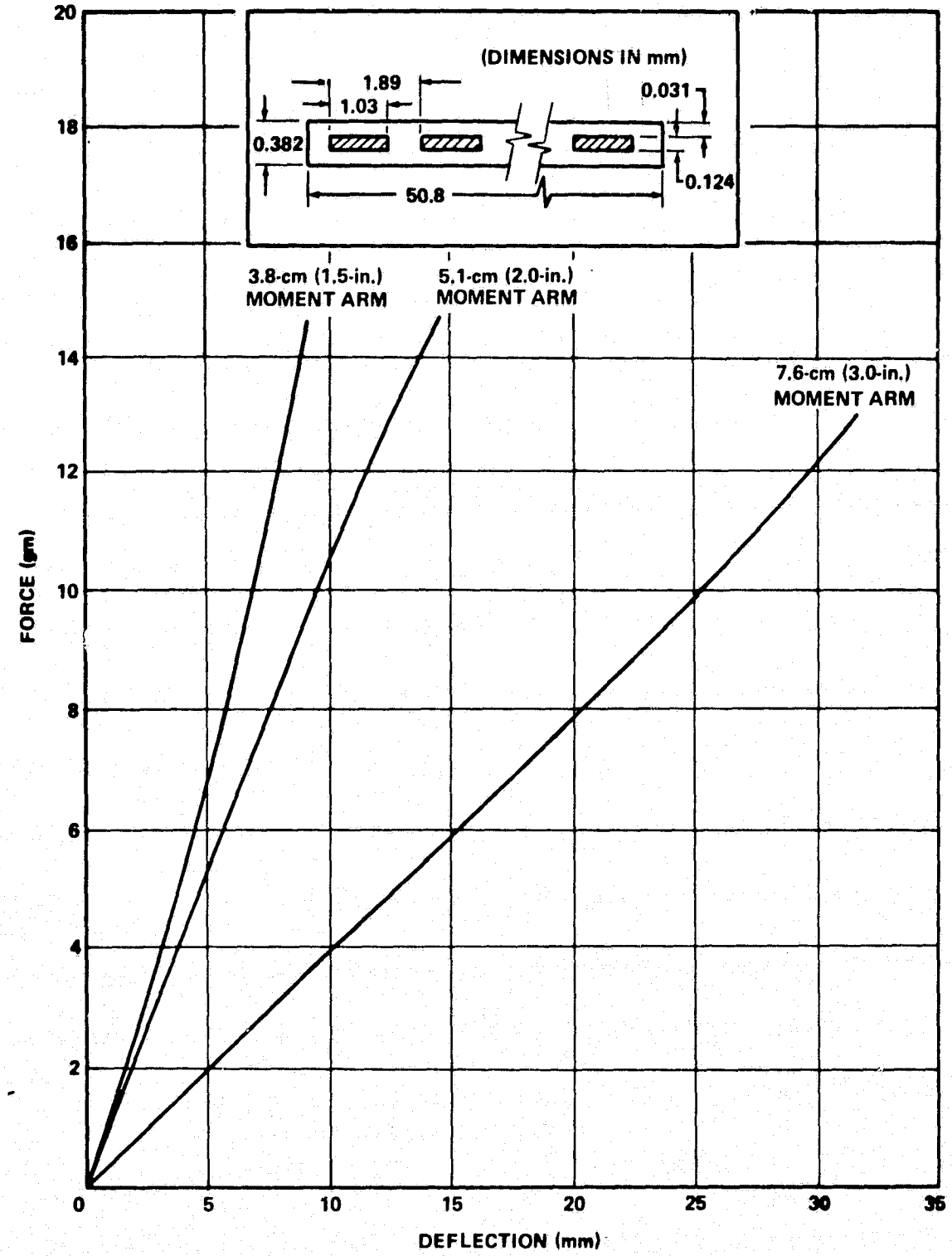


Figure 8. Force versus deflection characteristic for FCC sample No. 4.

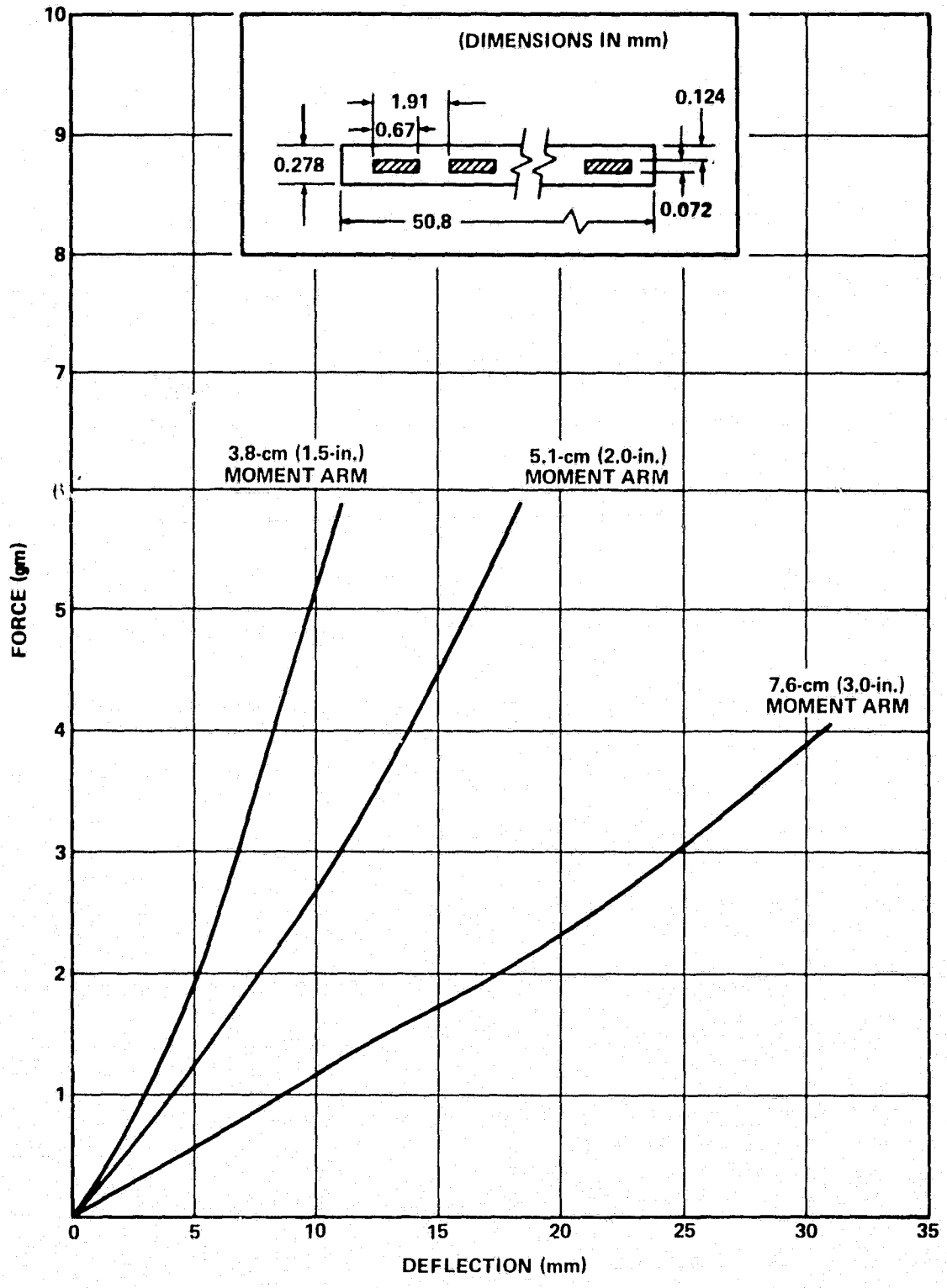


Figure 9. Force versus deflection characteristic for FCC sample No. 5.

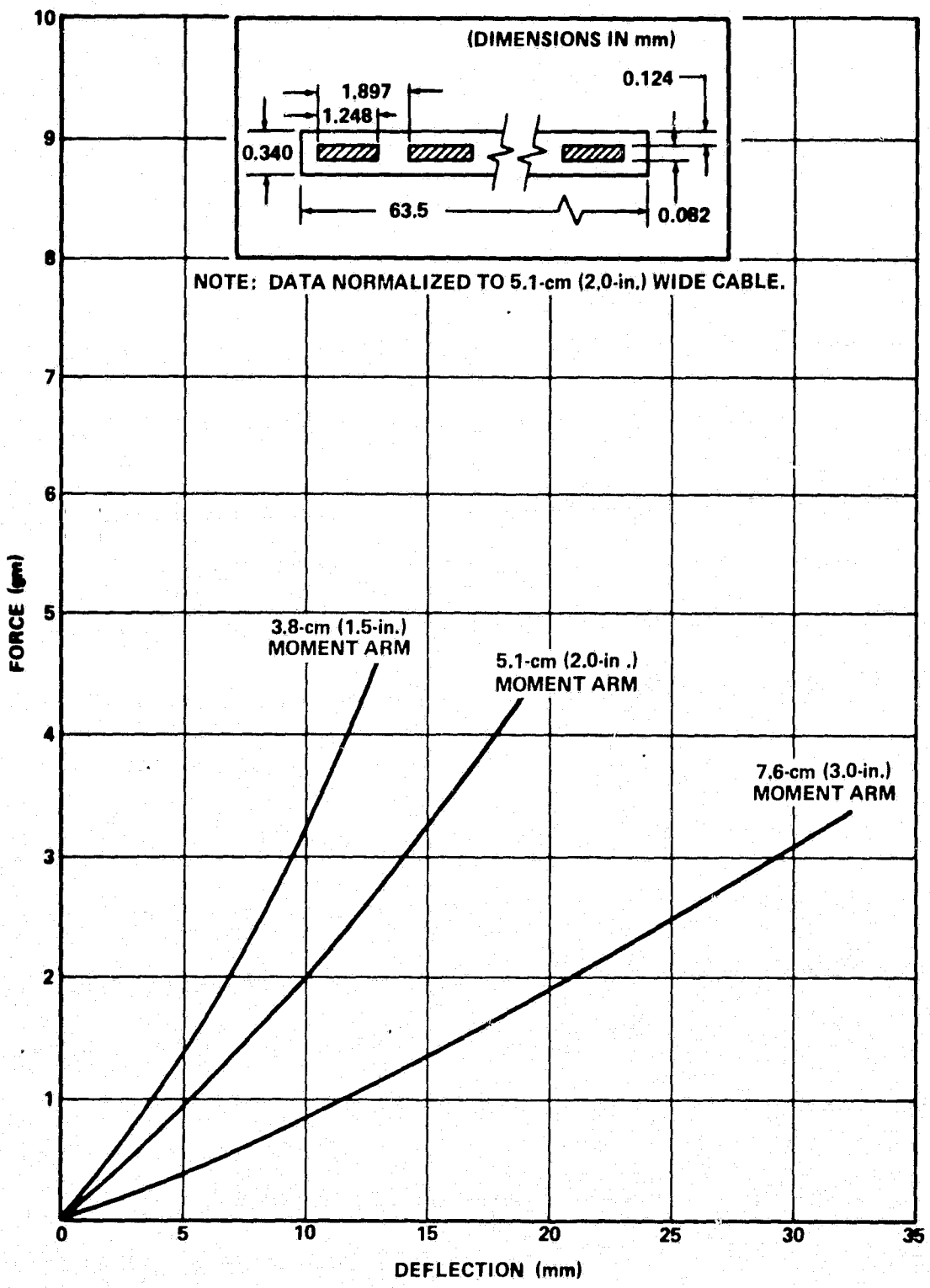


Figure 10. Force versus deflection characteristic for FCC sample No. 6.

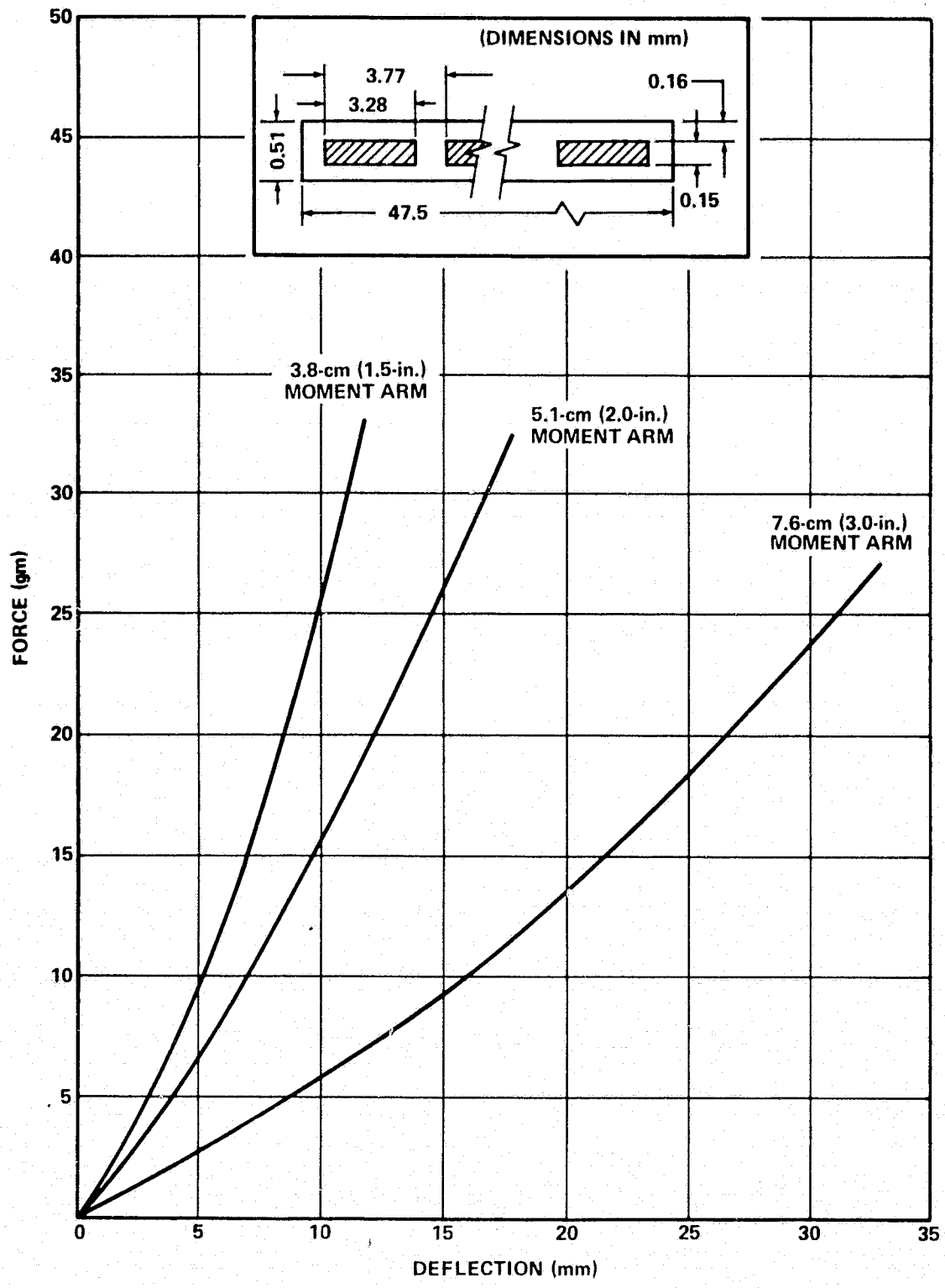


Figure 11. Force versus deflection characteristic for FCC sample No. 7.

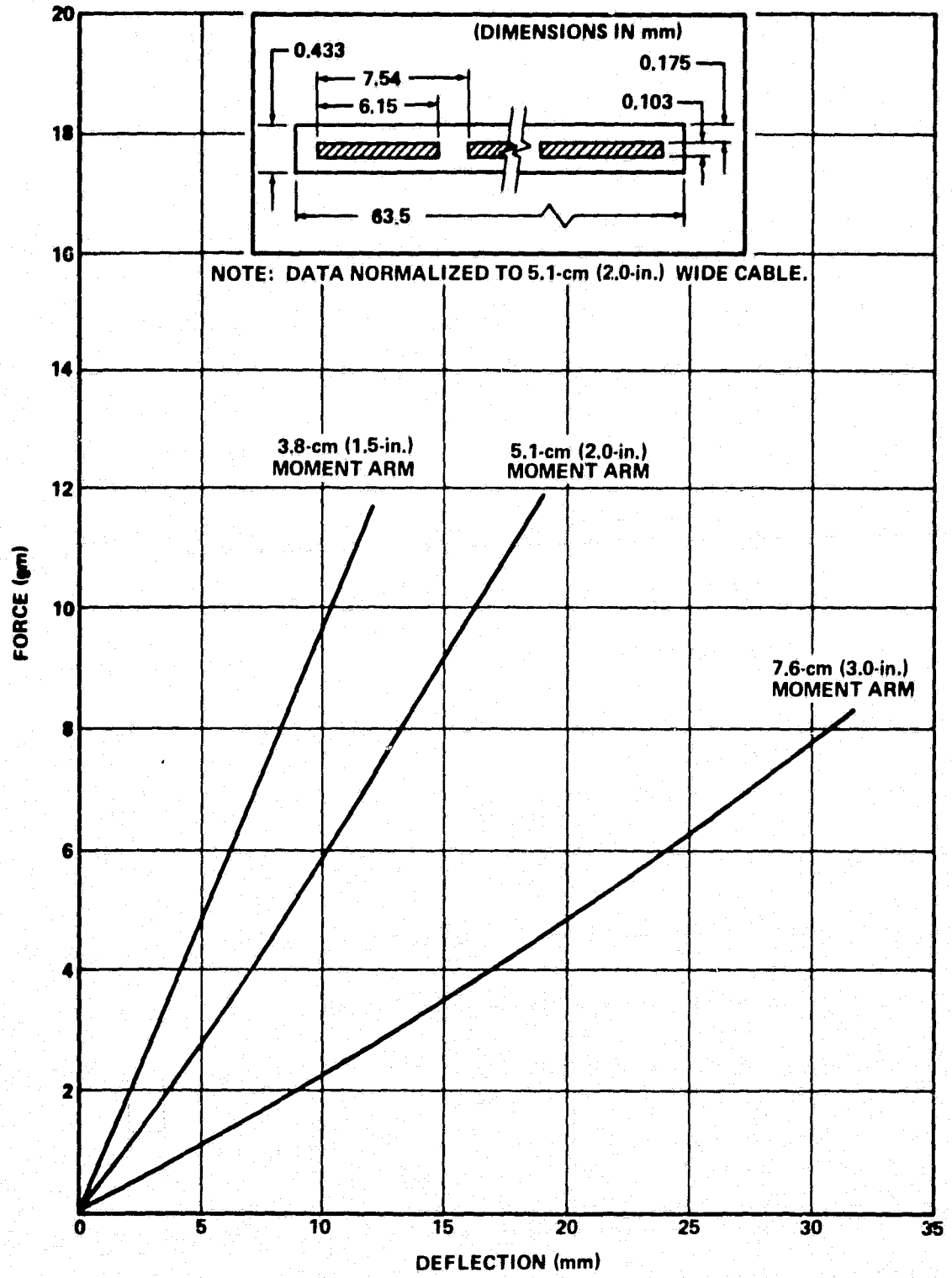


Figure 12. Force versus deflection characteristic for FCC sample No. 8.

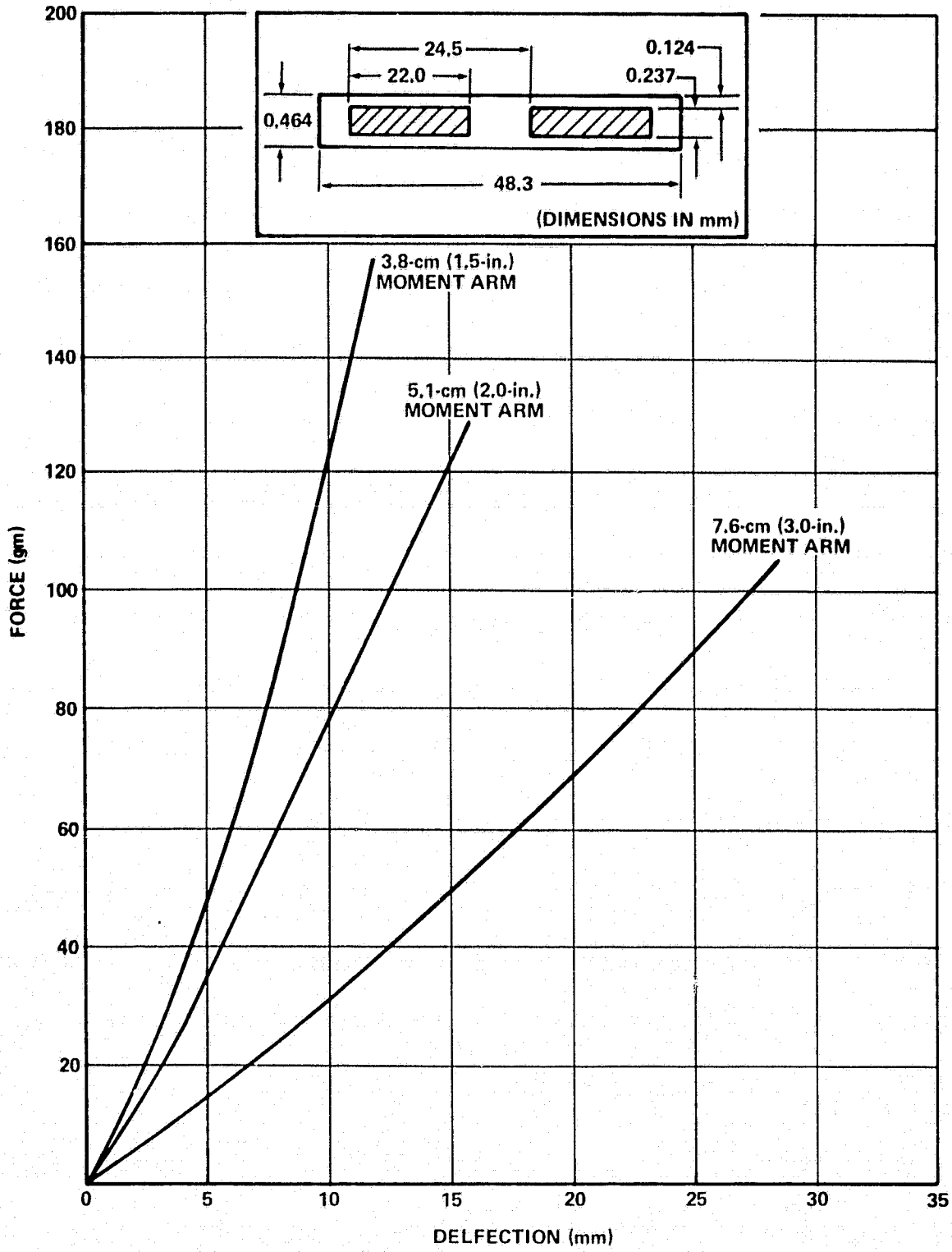


Figure 13. Force versus deflection characteristic for FCC sample No. 9.

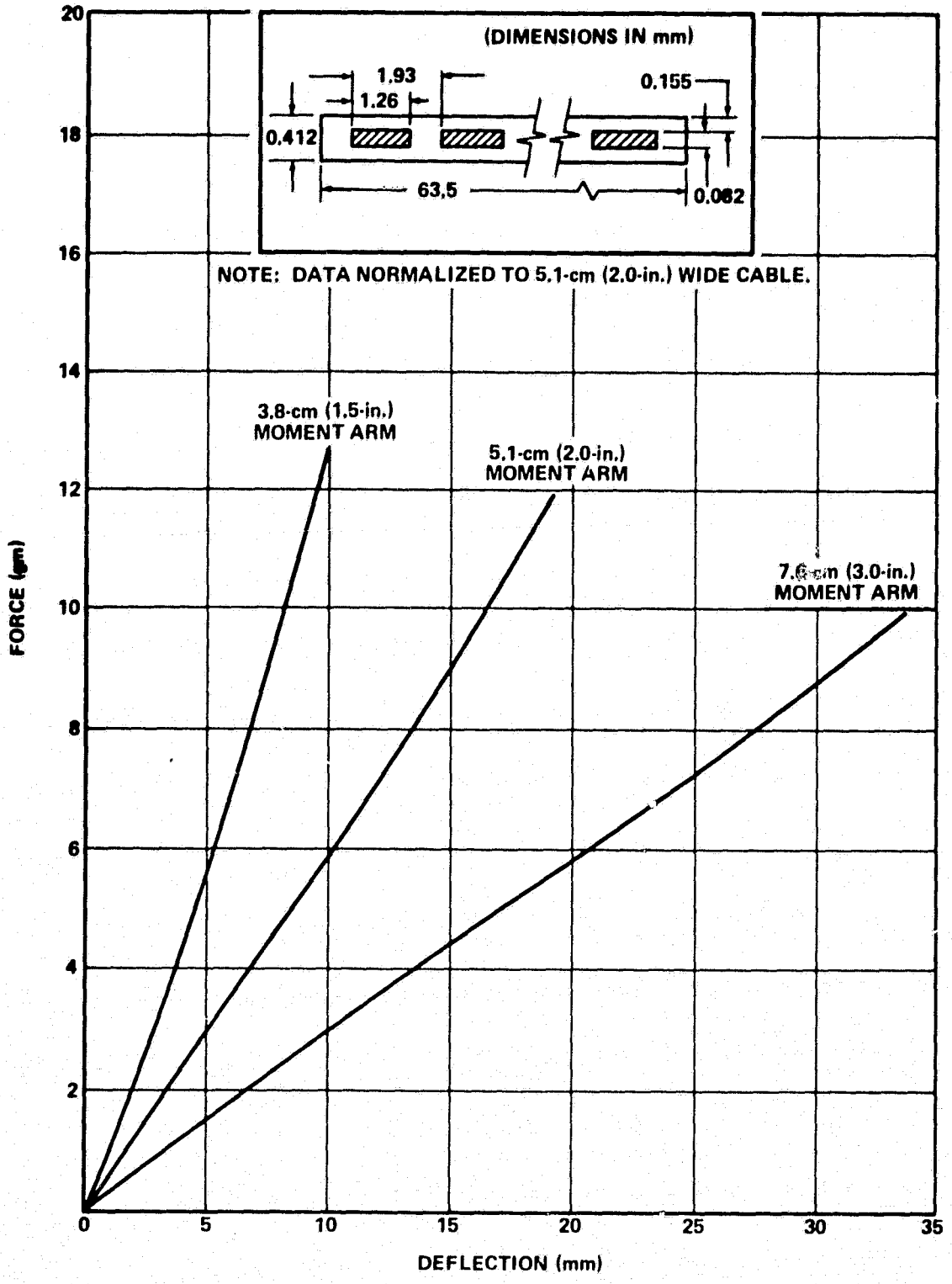
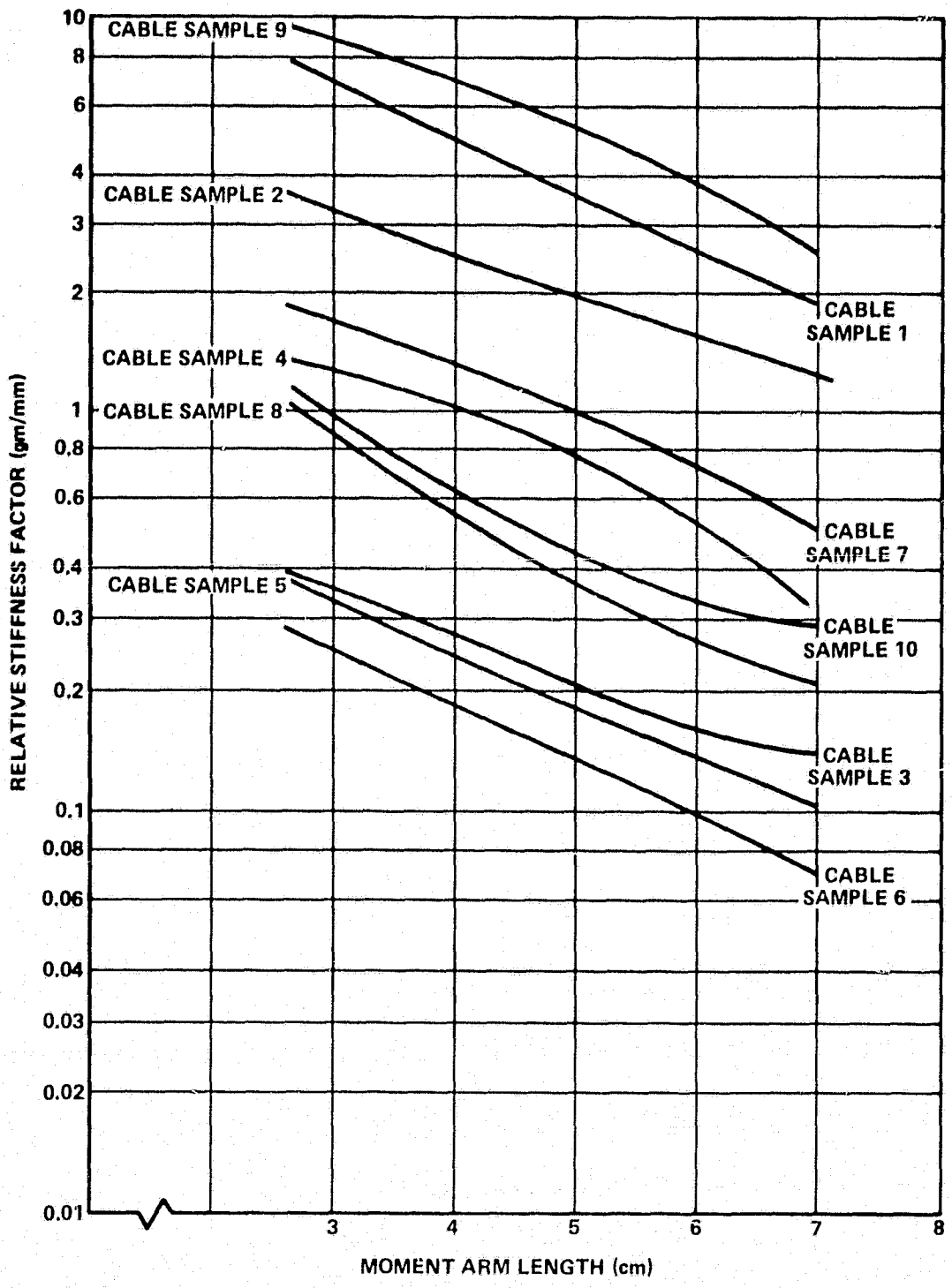


Figure 14. Force versus deflection characteristic for FCC sample No. 10.



* DATA NORMALIZED TO 5.1-cm (2.0-in.) CABLE WIDTH. TABLE 1 GIVES THE DATA IN TABULAR FORM.

Figure 15. Relative stiffness factor versus moment arm length.

APPROVAL

RELATIVE STIFFNESS OF FLAT CONDUCTOR CABLES

By James D. Hankins

The information in this report has been reviewed for security classification. The report, in its entirety, has been determined to be unclassified and contains no information concerning Department of Defense or Atomic Energy Commission programs.

This document has also been reviewed and approved for technical accuracy.

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