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TECHNICAL DIVISION - SECTION IV
J. A. Kyger - Chief

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Engineering Data on "MO" Shielding Concrete and Boron (Thermal Shield) Cement

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T. Rockwell
F. J. Roehrenbeck

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March 17, 1948

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Introduction

H. P. Sleeper, Jr. of General Electric's Atomic Power Laboratory at Schenectady, contacted the writers early in February 1948, regarding a magnesium oxychloride bonded iron aggregate shielding concrete mentioned in Rockwell's report to J. A. Kyger dated December 23, 1947. Sleeper suggested that this material might be of interest at Hanford, where new piles were under consideration. He noted that any information would have to reach Hanford in the near future to be of any use.

The writers replied that the material in question (designated as "M1" for "magnesium oxychloride, 1% boron by weight") was probably somewhat of a risk from the engineering standpoint, due to the boron-containing additive, and that for this reason age data could not be inferred from available information on fifty-year-old installations of oxychloride-bonded mineral aggregate concretes. It was proposed that a simple oxychloride cement with iron aggregate be tested.

Sleeper came to Oak Ridge and for two weeks round-the-clock-tests were run on engineering and nuclear properties of what was designated "MO". With the cooperation of the operating crew, the pile was run at low levels and shut off for long periods every day during these tests, and assistance was obtained from other sections (particulary R. N. Lyon) in running the mechanical and thermal tests.

The results of these and previous tests are the subject of this report. The radiation attenuation data are the subject of a companion report issued by the Physics Division.

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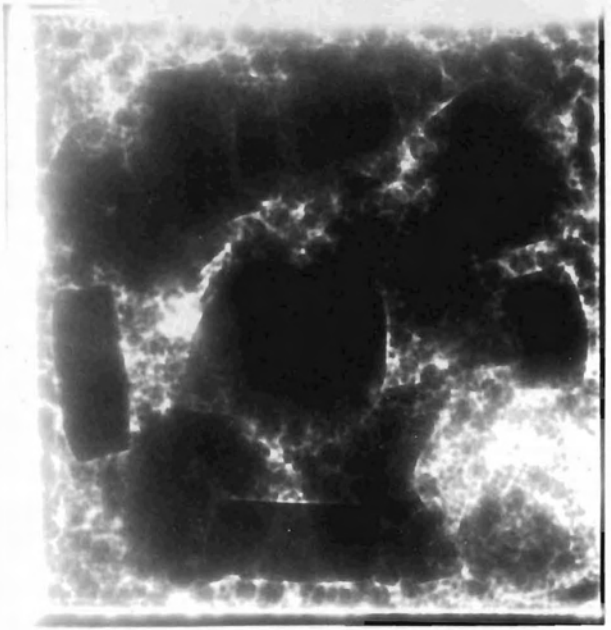
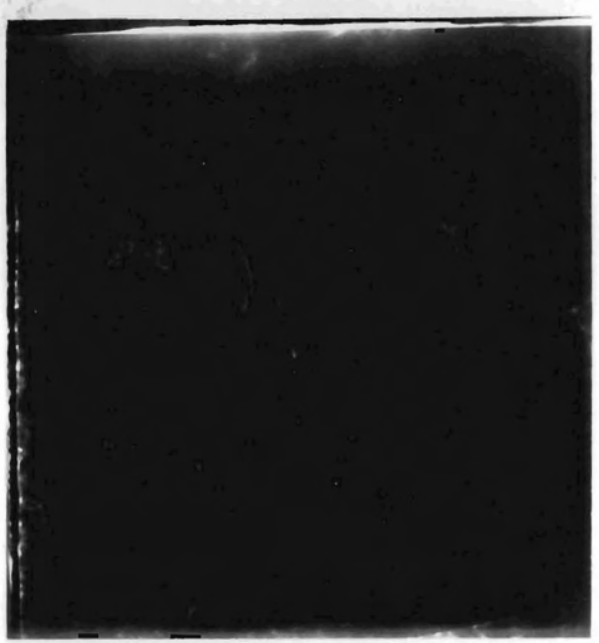
Typical Sections of M.O. Shielding Concrete





X-RAY POSITIVES THRU MO SHIELDING CONCRETE

LEFT: 1" THICK, 100 KVP (CORRESPONDS TO $\frac{3}{8}$" Fe)
RIGHT: 2" THICK, 140 KVP (CORRESPONDS TO $\frac{3}{4}$" Fe)

SIX MILLIAMP-MINUTES FOR BOTH PIECES

"MO" Composition

1. For a 1/3 yd.^{3} concrete mixer:

MgO	162-1/2 lb.
Steel Punchings, 3/4" x 3/4"	1000
Steel Shot, 1/8"	450
Steel Shot, 1/20"	300
Satd. Soln. (~ 32° Be) $MgCl_2$ -	16 gal.

This gives 6 ft.^{3} @ 360 # / ft.^{3}

2. This gives a concrete with about the following:

MgO	7.76% by wt.
$MgCl_2$	2.42
H_2O (bound to cement)	5.96
Punchings	47.8
Shot, 1/8"	21.6
Shot, 1/20"	14.4
	100.0

The oxide is 8-1/2% (wt.) of the dry mix.

The cement is 16-1/2% (wt.) of the concrete.

The cement is 53% (vol.) of the concrete.

The stable phase of the cement is thought to be $5MgO.MgCl_2.12H_2O$ and seems to run from 35-40% bound water by weight. A detailed report on the cementitious phase is forthcoming.

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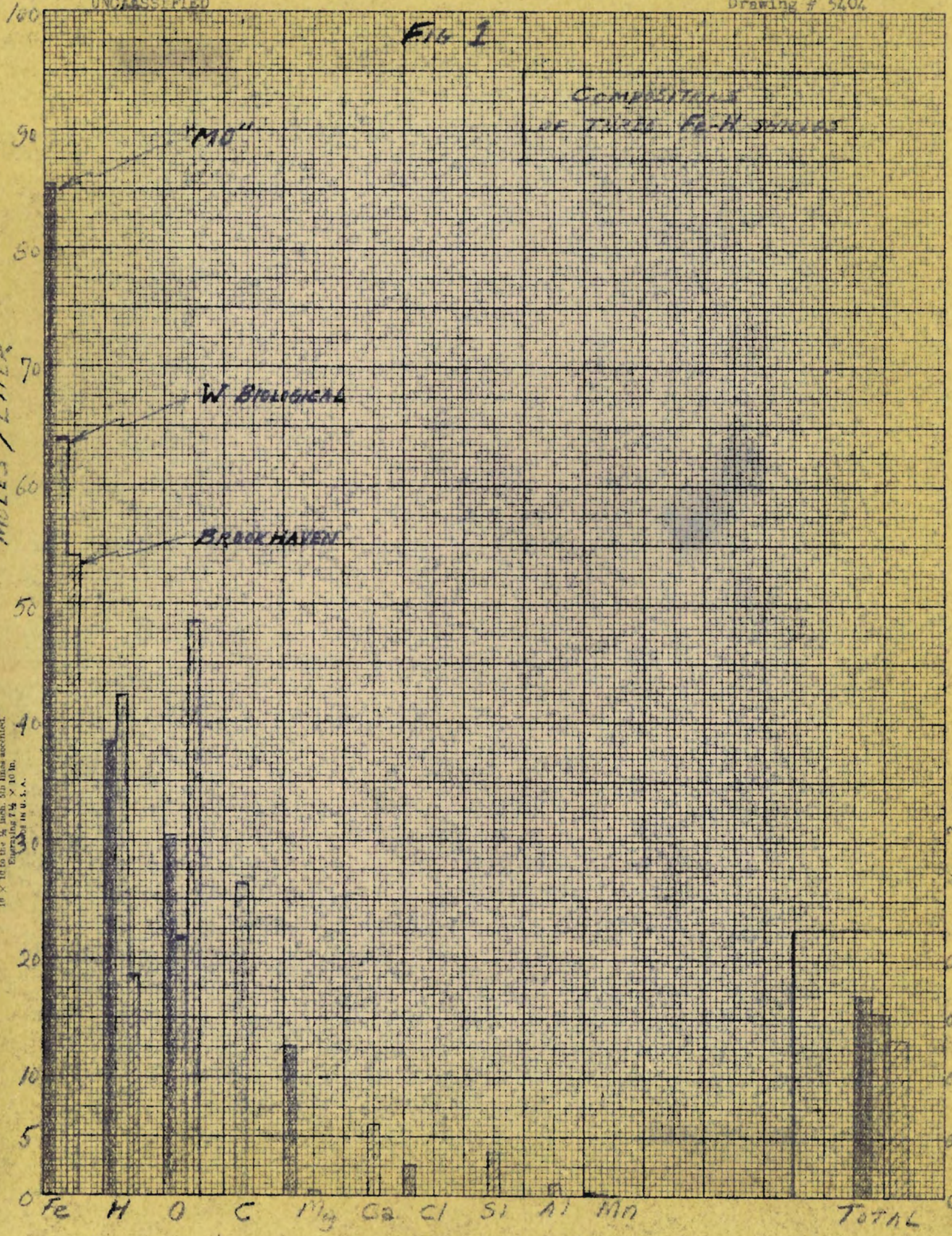

KEUFFEL & ESSER CO., N. Y. NO. 359-12
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3.

	Wt.%	g/cc	mol/liter
Fe	83.5	4.85	85.3
H	0.660	0.0383	38.3
Mg	5.27	0.305	12.69
Cl	1.81	0.105	2.96
O	8.40	0.487	30.4
Mn	0.345	0.0200	0.365
C,P,S	Traces	---	---

Cost

1. Cost of "MO" Shield

1 cu yd = 5 tons (9,720 lb.)

MgO @ 60 $/T

$60 \times 5 \times .0776 = \boxed{\$23.30/yd^3}$

$MgCl_2.6H_2O$ @ 37 $/T

$37 \times 5 \times .0242 \times \frac{203}{95} = \boxed{\$9.65/yd^3}$

Punchings @ 44.50 $/T

$44.5 \times 5 \times .478 = \boxed{\$106/yd^3}$

Shot @ 92 $/T

$92 \times 5 \times .360 = \boxed{\$167/yd^3}$

$\boxed{\$306/yd^3 \text{ for materials}}$

= $50/T = 2-1/2¢/#

[redacted]

Physical Properties

1. Mechanical

A. Initial set occurs in 2 to 4 hours

Essentially full strength is reached in 24 to 48 hours

2000 - 3000 psi compression strength is reached in 15 to 20 hours

Maximum setting rate occurs at 8 to 12 hours

Volume change on setting is reported (for similar mixes) as less than + .04% to - .05% max. (1/5 Portland*). No visible shrinkage cracks. Tests will be run on MO.

B. Density is 5.80 g/cc (2-1/2 times Portland)

360 lb/ft^3

5T/yd^3, homogeneous to ± 1% in 6" x 12" cylinders.

C. Compression Strength on ASTM 6" x 12" cylinders: 4-5000 psi (twice Portland)

Modulus of Rupture (bending 3 x 3 x 30" beam) - 1380 psi (4 times Portland)

Modulus of Elasticity = 250,000 psi (14 times as "springy" as Portland)

(The bulletin of the Oxychloride Cement Association says: "All types have high structural strength, with transverse strengths ranging from 1200 - 2400 psi and compression from 4000 - 8000 psi")

*"Portland" shall be used to designate a typical (e.g. 1-2-4) Portland cement concrete.

2. Thermal

A. Heat evolution (max) on setting is < 0.224 watts/lb (Probably less than Portland.)

B. Thermal Conductivity = 2.4 Btu/hr x ft^2 x (^oF/ft)

(Five times Portland)

(Roughly ten times W, across laminations, calc.)

C. Heat Capacity = 0.147 Btu/lb. x ^oF (calc.)

= 0.144 (exp.)

(comparable to Portland)

3. Stability

A. Aging: OCA Bulletins: ".....a properly selected oxychloride floor will improve with age, and may be classified as permanent... The longest records of continuous use have been in maritime service. These records go back 50 years with many installations outlasting the life of the ship.....The NYC Subway Systems have used it for over 25 years, and today are operating more than 3,000,000 square feet....."

B. Thermal: The thermal stability of oxychloride cement is considerably superior to Portland (see graph). The latter is considered structurally sound up to 500 ^oF (Hoole, "Concrete Engrs. Hbk."). Twenty-four hours at 220 ^oF result in no measurable reduction of crushing strength. Thirty day test now in progress.

C. Radiation: Tests are now in progress. No significant damage to the Clinton or other concrete shields has been observed. It seems reasonable that H_2 evolution from the MO shield would be comparable to W at the same flux, since the hydrogen concentration is comparable. It should also be noted that both neutron and gamma flux are lower at every point in MO than in W. Gas evolution (volume and composition) tests will be made at Hanford with samples supplied by ORNL.

BORON CEMENT

Boron Gamma

Data from the radiation test group indicate that secondary gammas, produced by thermal neutron absorption in the iron thermal shield, account for a large part of the Hanford gamma shielding problem. If an (n,α) absorber (e.g. boron) were substituted for the usual (n,γ) thermal shield, the gamma shielding problem, now serious, would be greatly eased.

For this purpose a boron cement was developed. It should be noted, when evaluating thermal conductivity, that 90% of the thermal neutrons will be absorbed in the first quarter inch, making the mean heat path to the inside face of the cement very small. The total heat flux is only 75 w/ft^2 (comparable to the load on the walls of a fluorescent light tube) for this n,α reaction. Thermocouple readings at Hanford indicate only an 85 w/ft^2 load in the iron, giving a 2 ^{o}C temperature rise in 300 gpm of cooling water at 275 MW, including radiant heat transfer from the pile.

Data on this boron cement follow.

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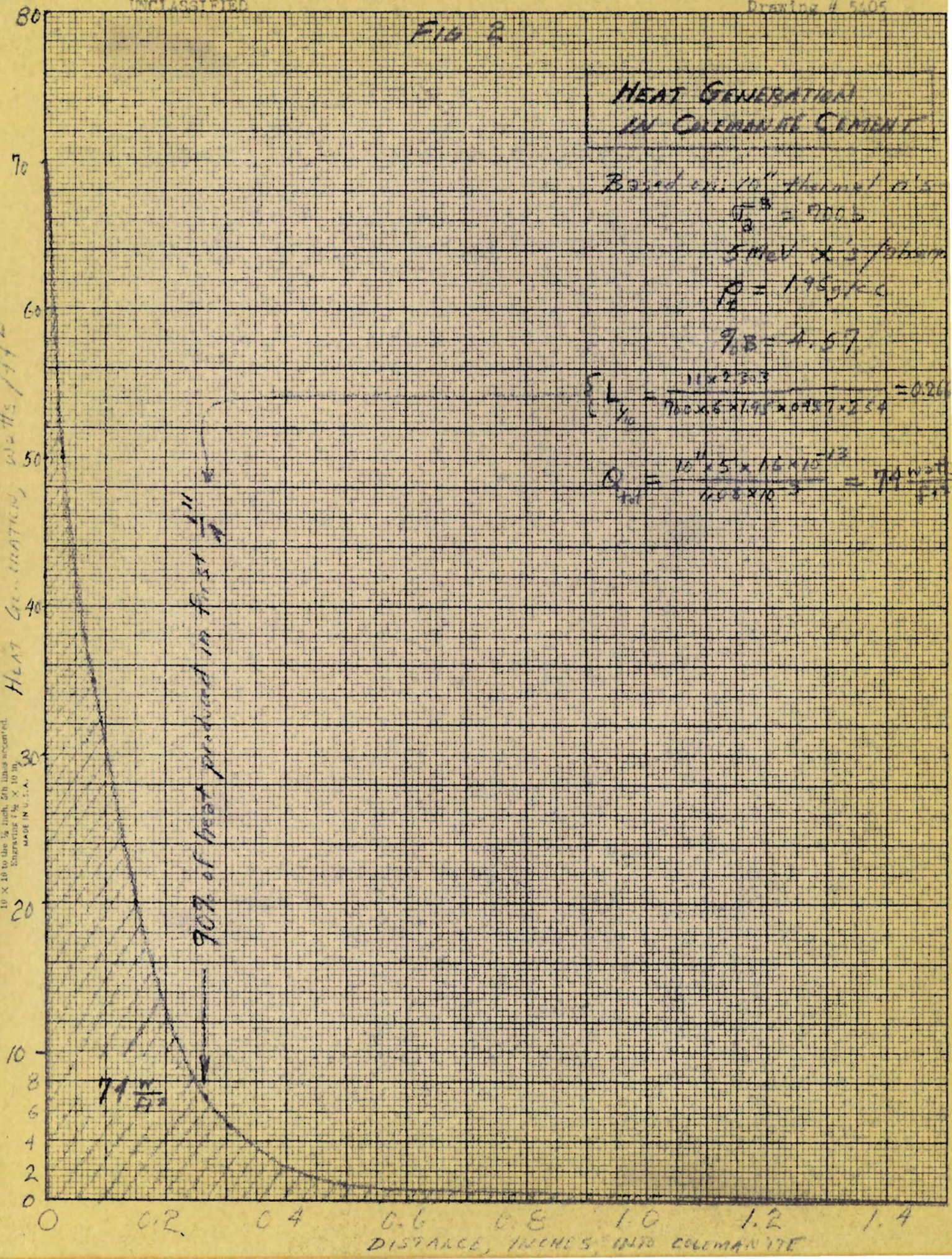
Drawing # 5105



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Composition

Equal weights of MgO and Colemanite ($2CaO.3B_2O_3.5H_2O$) are gaged with saturated $MgCl_2$ solution to make a cement with the following composition:

1.

MgO	28.1% by weight
Colemanite	28.1
$MgCl_2$	13.4
H_2O	30.4
	100.0

2.

	Wt%	g/cc	Mol/liter	g/cm^2 for 2"
B	4.44	0.0865	7.98	0.440
H	4.06	0.0791	79.1	0.402
Mg	20.21	0.394	16.42	2.00
Cl	10.01	0.1951	6.93	0.992
O	55.8	1.090	68.2	5.54
Ca	5.47	.1066	2.66	0.541
Total	100.0	1.95	181.3	9.92

3. To increase strength and thermal conductivity, aluminum turnings may be added to the mix. As little as 4-5% by weight (7% by volume) will greatly improve these properties with no increase in cost and negligible effect on shielding efficacy.

Physical Properties

1. Density: 1.95 g/cc

   20 lb/ft^2 for 2" slab

2. Compression Strength: 1500 psi. plain

   3540 psi with 5% (wt) Al

   (730 psi for Colm:MgO = 2:1)

3. Modulus of Elasticity: 66,900 psi plain

   178,000 with 5% Al

   (20,200 for 2:1)

4. Thermal Conductivity: 0.51 Btu/hr x ft^2 x (^oF/ft) plain
   0.63 with 5% Al
   (ordinary concrete = 0.45 - 0.55)

(Note: Mean path for heat to inside face will probably be of the order of 1/4 inch, since 90% of heat generation occurs within first 0.266".)

Cost

1. Cost of 2" Colemanite Cement Slab

   1 yd^2 = 3 x 3 x 1/6 = 1.5 ft^3

   1.5 x 62.4 x 1.95 = 183 lb/yd^2 (= 0.0915T)

   MgO: 60 x .0915 x .281 = $1.54

   Colemanite: 77.5 x .0915 x .281 = $2.00

   $MgCl_2 \cdot 6H_2O$: 37. x .0915 x .134 x $\frac{203}{95}$ = $0.97

   Total $4.51/$yd^2$ ($3600 for 800 yd^2)

   Note: This is probably 1% of cost of present thermal shield. The Al turnings will not increase the cost, since their price is the same as the volume of cement they replace.

APPENDIX: Engineering Tests

1. Mechanical

A. Initial set obtained by inspection

Full strength from heat evolution curve (q.v.)

Maximum setting rate, same

Volume change: Specs. of Oxychloride Cement Association

B. Density from 6" x 12" ASTM compression cylinders. Homogeneity from fact that sample cylinders taken throughout run weighed 72 lb, ± 1/2 lb. Other runs within one pound.

C. Compression Strength: 6" x 12" ASTM cylinders, capped, cannot be broken with 60 ton machine (4200 psi). Battelle data on similar mixes, our data on hydraulic press, give 4-5000 psi. (ASTM - C-39-44)

Modulus of Rupture: Bending 3 x 3 x 30" beam on Baldwin-Southwark tensile compression machine (60T).

(ASTM D-143-27 Modified)

Modulus of Elasticity from both compression cylinders and beam test.

2. Thermal

B. Thermal Conductivity was obtained by casting a 6" diam. x 12" long cylinder with a Calrod heater centered on the longitudinal axis and thermocouples at various locations (method of R. N. Lyon). A known amount of power was supplied to the Calrod, the thermocouples were allowed to come to equilibrium, and the conductivity was calculated from the following equation:

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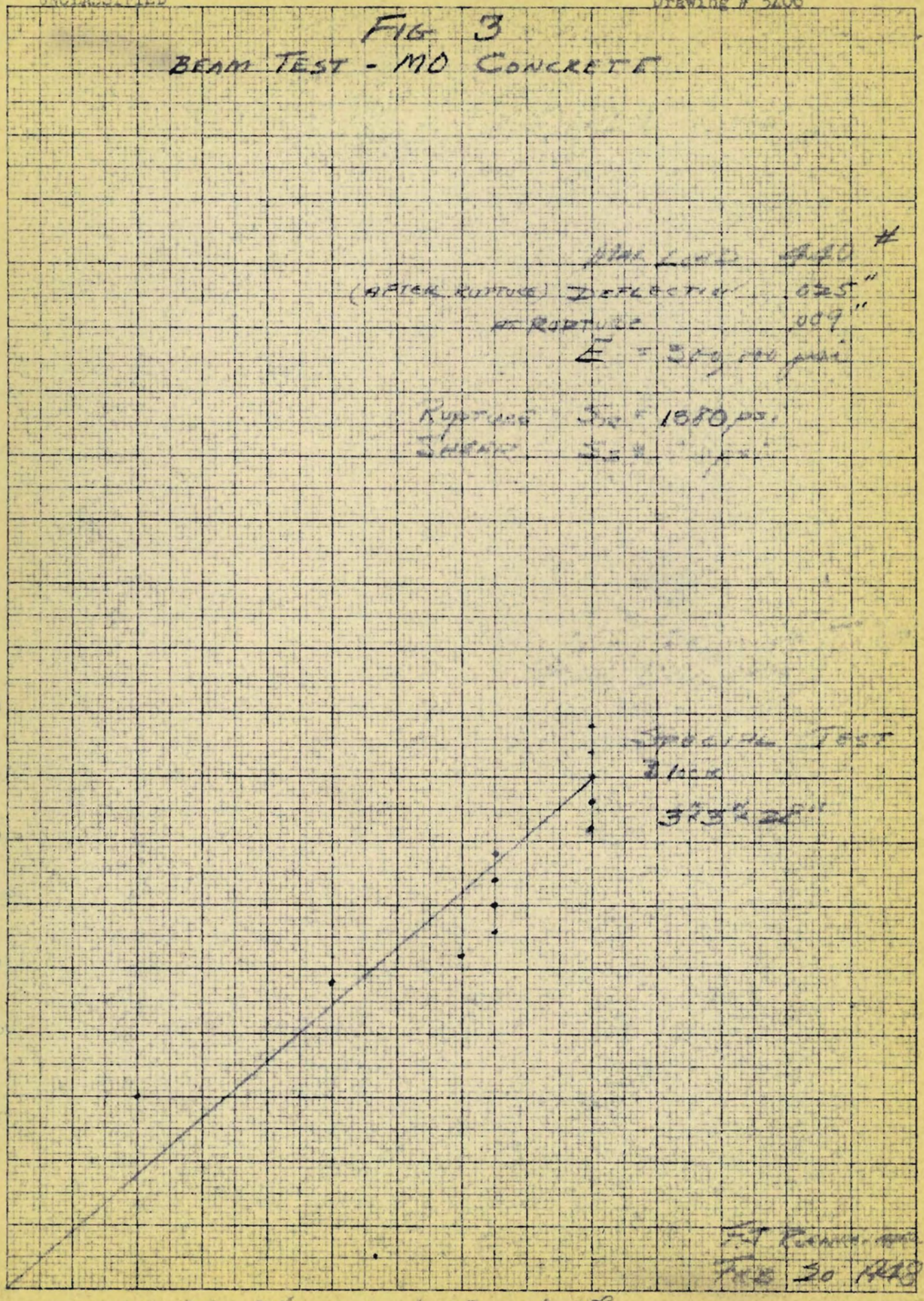
Drawing # 5106

FIG 3
BEAM TEST - MO CONCRETE



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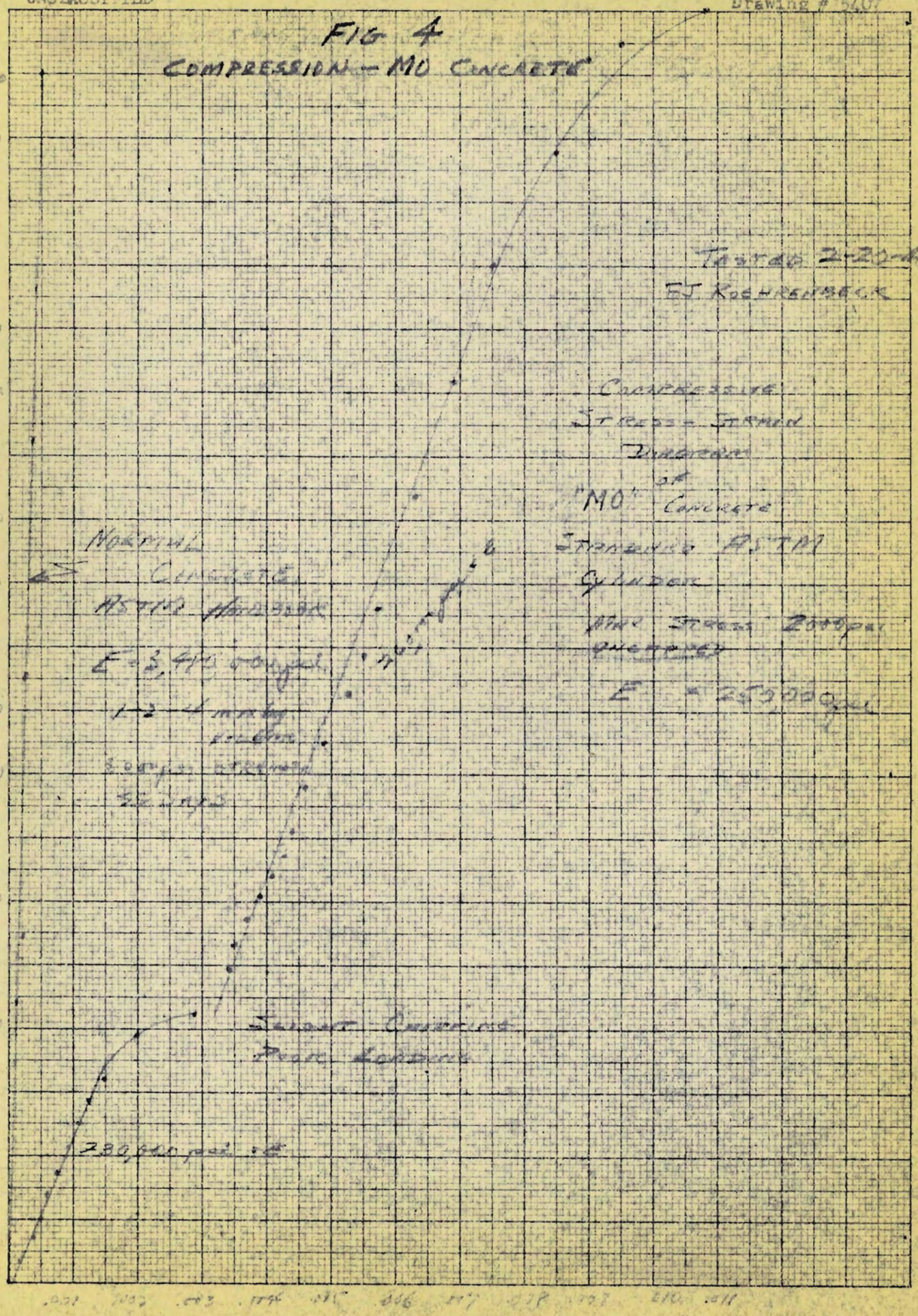

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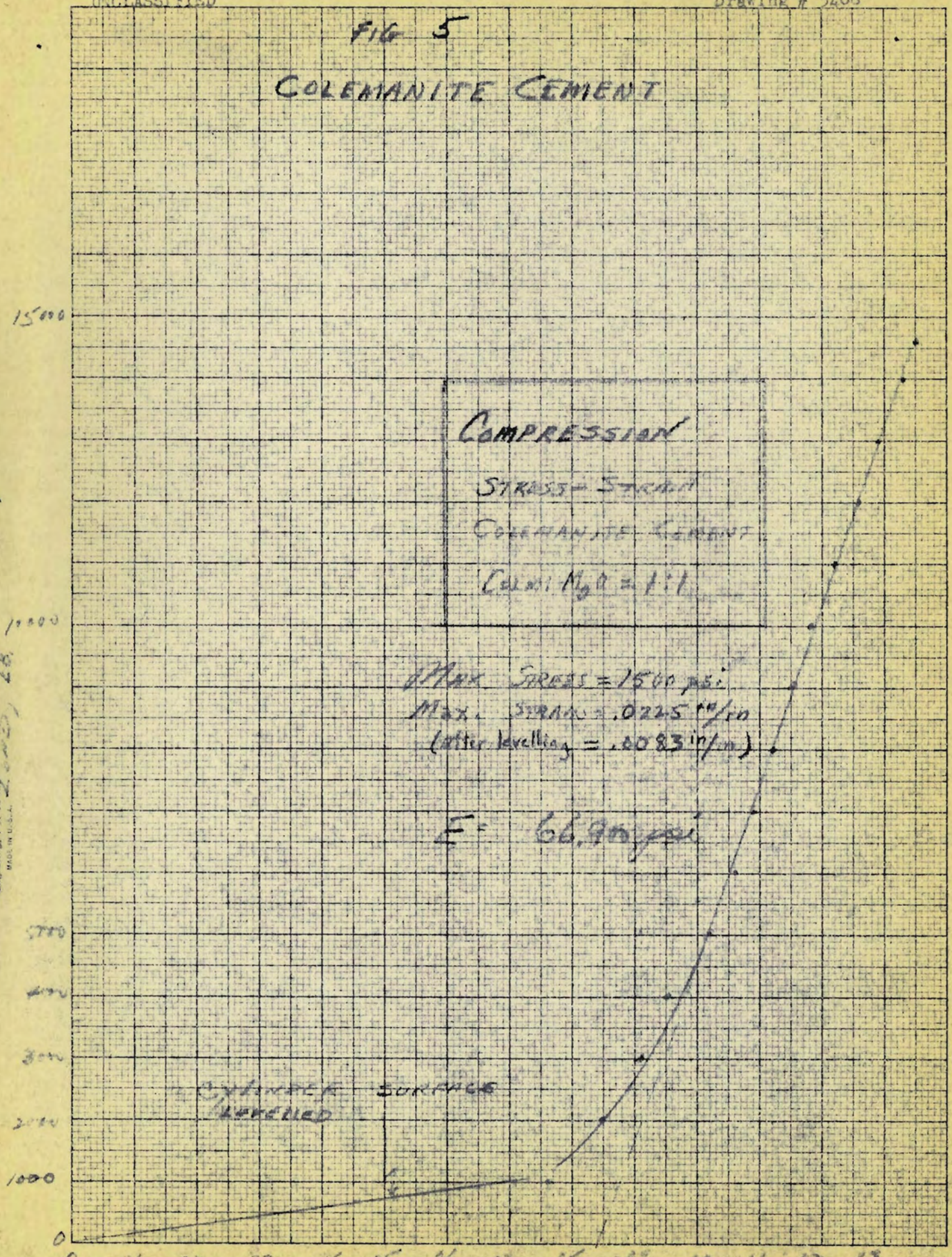
FIG 5

COLEMANITE CEMENT



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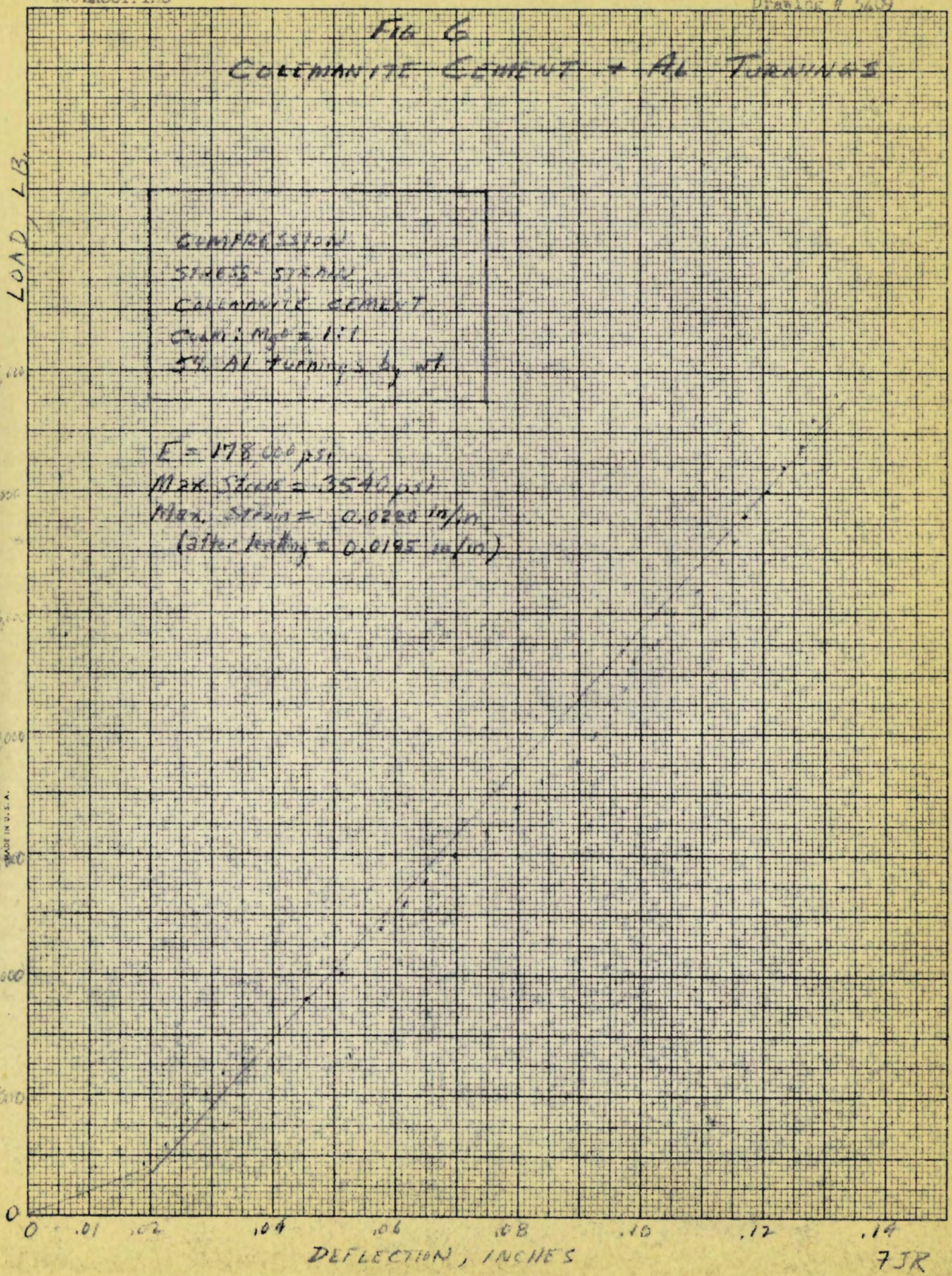
Drawing # 5409

FIG 6

COLEMANITE CEMENT + Al TURNINGS



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$$\frac{d(\text{temp})}{d(\text{radius})} = \frac{\text{heat production /time x length}}{2\pi \text{ radius x conductivity}}$$

from which

$$K = 27.45 \frac{I^2(\text{in amps})}{T\ (^{o}F)} \quad \text{Btu/hr x ft}^2 \text{ x } (^{o}F/\text{ft})$$

A. Heat evolution was computed from thermocouple readings on the thermal conductivity cylinders, without power in the Calrods, during setting. It was observed that the heat evolution was insufficient to maintain a one degree centigrade drop between the center and the outside. From Young's formula (MonP-147) for temperature drop in a cylinder with uniform heat generation:

$$\text{Heat Production} = \frac{4 \text{ x conductivity x } \Delta T}{(\text{radius})^2}$$

C. Heat capacity (exp.) was obtained by heating four 100g specimens (with no punchings but all of the iron as small shot) to 100 °C for four hours, then dropping each into 200 cc of water. The calculated value, given for comparison and checking to 2%, was obtained by adding the weighted values from the handbook for Fe, MgO, $MgCl_2$, and H_2O, based on 83.5% Fe, 16.5% $5MgO.MgCl_2.12H_2O$.

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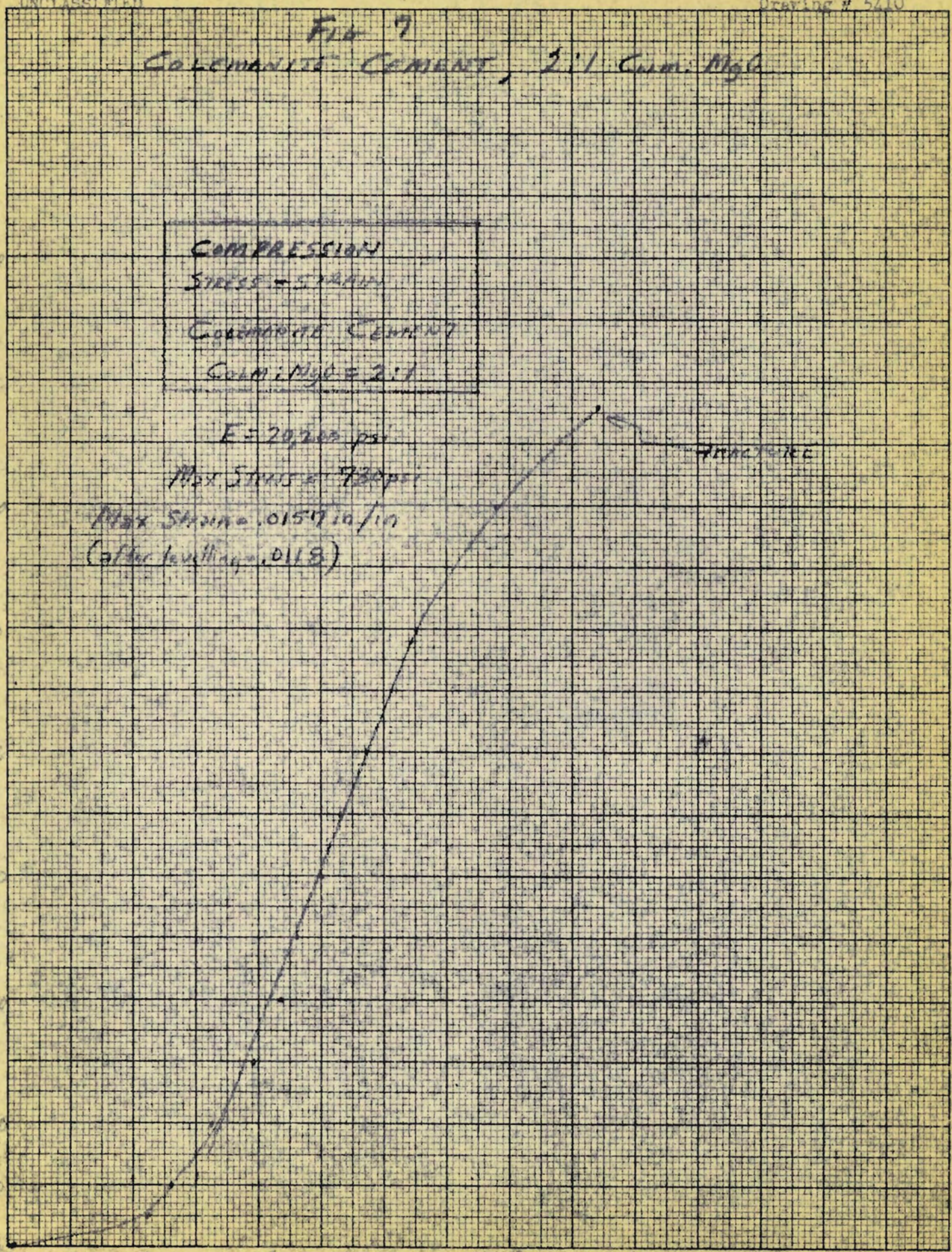
Drawing # 5410



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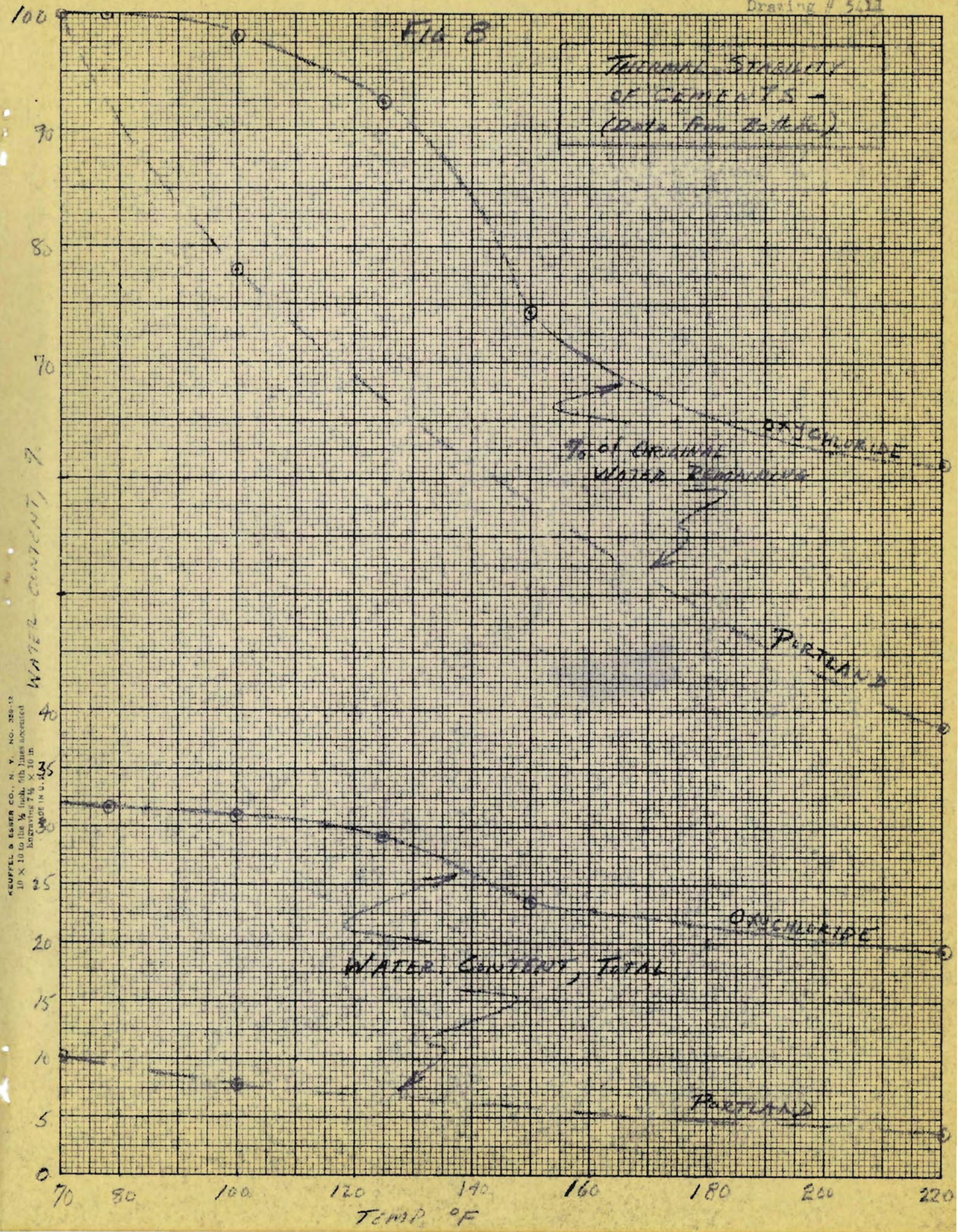

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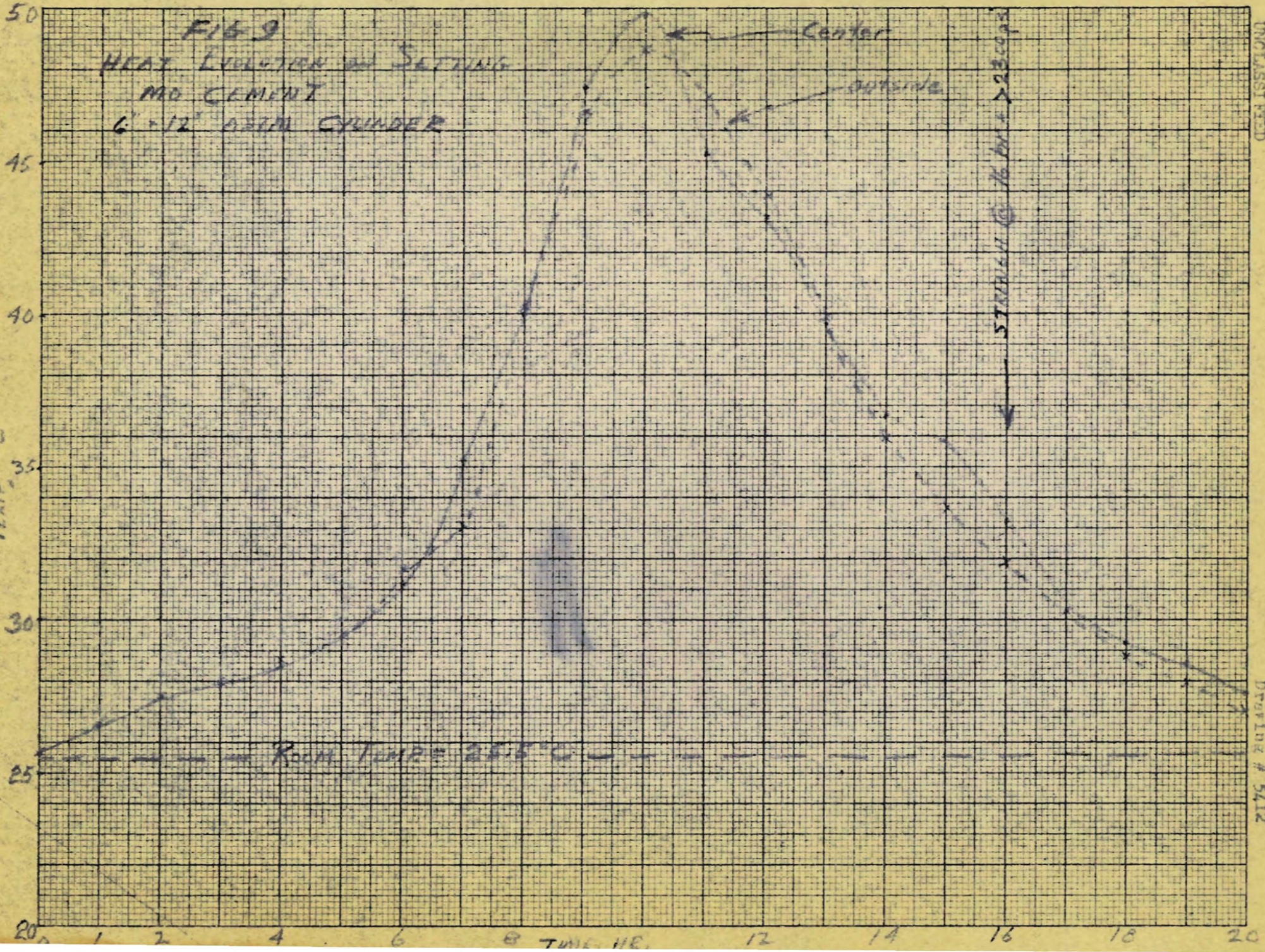

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