THE DEVELOPMENT AND USE OF STRUCTURAL GYPSUM

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ARMOUR INSTITUTE OF TECHNOLOGY

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Development and use of structural gypsum
THE DEVELOPMENT AND USE OF STRUCTURAL GYPSUM

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General Consideration of Gypsum.

Gypsum and Gypsum plasters have been known since ancient times. The Egyptians used Gypsum in the building of pyramids more than 4000 years ago, and for their finer work they used a calcined plaster precisely similar to the Plaster of Paris of modern times. The Greeks also used calcined plaster in making casts, the earliest known use for this purpose.

In Europe they have used a white compact variety of Gypsum known as "Alabaster" for centuries, mainly for interior decorations, statues and mural decorations.

The Gypsum industry first appeared in the United States in the State of New York at the time when the population was mostly restricted to the Atlantic seaboard. As the population moved westward, Gypsum deposits were soon found and developed in Michigan, Iowa, Kansas, California and other States. So the use of Gypsum has developed in its crude and calcined forms up to the present day.

While structural Gypsum has been used in this country for but a few years (three to six), it has been used extensively in Europe for centuries. The European system is based on the use of "dead burnt" Gypsum, that is calcined to a point of 650°F. or more, while the American method makes use of Gypsum calcined
at a temperature of about 400 F. Although the highly calcined or dead burnt materials give the greatest strength, the careful preparation and watching which the material requires in addition to the very slow setting property (two to four weeks), makes its use not adaptable to American methods of quick results and efficiency.

Gypsum is mined or quarried in the form of a comparatively soft rock, containing more or less impurities. It consists of hydrous calcium sulphate, that is sulphate of calcium with water of crystallization and is expressed by the formula CaSO₄·2H₂O.

In the process of manufacture the rock is crushed and ground up and then calcined. This consists of driving off the water of crystallization. The residue is called "Plaster of Paris", "Commercial Gypsum" or "Structolite", depending on the purity of the rock and the extent of calcination.

The addition of water to any of the above allows crystallization to take place again and a resulting mass more or less like the original rock is obtained. The degree of strength of the resulting hydrated Gypsum depends first - upon the amount of water of crystallization given off in calcination, and second - on the amount of water added in hydrating, or, setting up the Gypsum.
In Gypsum to be used for non-structural purposes, such as hard wall plaster, Plaster of Paris, etc., the calcination is carried up to about 330°F., while for structural purposes, "Structolite", a temperature as high as 400°F. is reached before the dehydrate is drawn off.

"Structolite" is also called "Second Settle Stucco" or "Second Settle Gypsum" and receives these names because of the behavior of the Gypsum rock particles while being heated in the calcining kettles. During the early stages of the calcining process, the application of heat together with the constant stirring causes violent boiling, which quiets down or "settles" when the calcination reaches a certain point. This is the "First Settle" stage. By proceeding with the calcination to a higher temperature, the mass again boils violently, giving off more water of crystallization, which continues to a certain point when it again settles. This is the "Second Settle" stage at which point the calcination stops.

This second settle stucco was first used structurally in the form of reinforced Book tile to be used on roofs. See following illustration and detail of tile:
UNDERSIDE OF GYPSUM ROOF DECK SHOWING
3" x 12" x 30" SOLID TILE RESTING ON
TEE IRON SUB PURLINS.

DETAIL OF 3" x 12" x 30" ROOF TILE
The quantity, size and spacing of the reinforcing used in these tile was the result, not of any engineering calculations, but of a cut and try method, until a satisfactory result in strength was secured.

These tile met with such favor among the building trade and architects in general that one of the larger Gypsum Companies investigated the possibilities of using Gypsum for spans greater than 30 inches.

As there was no reliable data available on the structural properties of Gypsum, it was necessary to make a series of tests covering a very broad field and from them formulate a theory for calculation of the resistance to bending of reinforced Gypsum. These tests extended over a period of three years and were conducted mainly at the University of Illinois, Lewis Institute and in the Laboratory of the United States Gypsum Company.

This series of tests consisted first of an investigation of the various physical properties of the material, such as compression, modulus of elasticity, shear, bond and tension.

While we will discuss each of the above properties and give the results of a few typical tests, we will not attempt to tabulate all the results, as the number of specimens tested ran well up into the thousands.
Properties of Structural Gypsum.

Compression

The compression tests were made on cylinders 3" in diameter by 6" deep—and 6" diameter by 12" deep.

It was known that the strength of the set up gypsum depended greatly on the amount of gaging water used to set up the dehydrated material (called stucco), so a series of tests were made on cylinders mixed with varying percentages of water. Fig. I shows the results of the test.

It was found that a mix composed of 36% of water and 64% of stucco gave a sufficient strength and was still liquid enough to be able to pour nicely. For this reason this percentage was adopted as standard and is known as a mix of "normal consistency."

Age tests were next made on cylinders made of a mix of normal consistency. Results are shown in Fig. 2. It was soon found, however, that the strength did not depend so much upon the age but upon the amount of free moisture still held in the specimen.

Fig. 3 shows the strengths of cylinders with various percentages of excess moisture driven off. As the strength varied directly with the percentage of excess water, with no regard to age, it was decided that a maximum strength
FIG. 1

3 x 6 in Cylinders
Kiln Dried 100°F
Second Settle Gypsum

Compressive Strength in lbs. per sq. in.

Percentage of Water
FIG. 2

Compressive Strength in lbs per sq. in.

3 x 6 in Cylinder Kiln Dried 100°F
Second Settle Gypsum

Age at Test in Days
FIG. 3

Curve shows the increase in strength with the loss of excess water added at time of hydrating.

3"x6" cylinders Second Sette Gypsum Standard Consistency
was attained only when the material was 100% dry.

Fig. 4 shows the result of immersing specimens in water. This bears out the idea that the strength varies with the amount of free water present. It was found that the strength dropped to about half when the specimen was entirely soaked, and fell off gradually under further soaking.

After giving careful consideration to the foregoing it was decided to adapt a working stress of 350#/ per square inch in compression.

Tension

The tension test were made upon bricquettes very similar to the standard concrete bricquettes used for this purpose.

The averages are slightly over 300#/ per square inch ultimate, and are shown in the curve Fig. 5—page 12. It will be seen that the tension too varies with the amount of gaging water used.

On account of the relatively low tension strength, no valve is given it in computing beam design, that is, the straight line formula is used.

Shear

Very few tests of pure shear have been made for the reason that most of the shear values were taken from a series of beam tests.

The following results were obtained from a test made on 4 blocks 8" x 8" x 16" , when tested for pure
**FIG. 4**

Second Settle Gypsum

Days immersed in water

Compressive strength in lbs per sq. in.
FIG. 5

Tensile Strength

Percentage of water

Tensile strength in lbs per sq.in.
shear. The blocks were placed on two steel bars 3 1/4" to 3 1/2" apart—the load was applied to another bar placed on top of the block, directly between the two lower bars as shown in the following figure:

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Load (lb)</th>
<th>Shear (lb)</th>
<th>Total Area in Shear per sq. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen #1</td>
<td>13000</td>
<td>128</td>
<td>101</td>
</tr>
<tr>
<td>Specimen #2</td>
<td>18751</td>
<td>128</td>
<td>147</td>
</tr>
<tr>
<td>Specimen #3</td>
<td>15230</td>
<td>128</td>
<td>117</td>
</tr>
<tr>
<td>Specimen #4</td>
<td>19500</td>
<td>128</td>
<td>152</td>
</tr>
</tbody>
</table>

Average shear 129# per sq. in.

Bond

Bond tests were made with 1/2" bars embeded in 8" x 8" cylinders. The average for the dry specimens being about 500# per square inch. It was found that the bond stress varied directly with the amount of gaging water as shown in Fig. 6 — page 14.

The most striking feature in the entire series of tests was the way in which the bond stress fell off with increasing percentages of excess water.
FIG. 6

Bond Stress

Second Settle Gypsum
\( \frac{1}{2} \) in. plain round bars
Tested dry - age 74 days.

Bond Strength lbs. per sq. in.

Percentage Gaging Water.
This is shown clearly in Fig. 7. It is for this reason that the low value of 30# per sq. inch is used as a working bond stress.

Modulus of Elasticity

The modulus of elasticity was determined from specimens of normal consistency, and was found to be an average of about 1,000,000# for dry specimens. Fig. 8 shows how the modulus varies with the percentage of gaging water. The value of 1,000,000# is used in all calculations.

Some of the general properties of structural gypsum are: Weight 77# per cu. ft., low coefficient of thermal conductivity (about 1/3 that of concrete), slightly soluble in water (at 32°F one part in 368). It is also a good fireproofing material.

Theory Governing the Design of Structural Gypsum

Since the physical properties of the material compared quite favorably with concrete, it was decided to base calculations on a modified form of reinforced concrete theory. The notation used was quite similar to that used in "Principles of Reinforced Concrete" by Turneaure & Maurer.

On the following page is listed the notation used, and also the various working stresses.

For a steel stress of 16,000# per square inch, n 30, and a Gypsum stress of 350# per square inch in compression, the values of p–j–k have been worked out.
FIG. 7

BOND STRESS

Second Settle Gypsum

1/2 in. plain round bars
Original mixture
36% water
64% calcined Gypsum
Total excess water about
23% of weight of dry
specimen.

Bond Strength, lbs. per sq. in.

Age 1 da.
Age 7 da.
Age 28 da.
Age 22 da.

Excess Water Dried Out in
Percentage of Total Excess
FIG. 8

Modulus of Elasticity

Average Modulus of Elasticity in 100,000 lbs. per sq. in.
Page 19 shows the values of $j$ and $k$ plotted for various values of $p$ (percentage of steel).

In practice it is usually found that the governing factor in determining the amount of steel required, is not the tensitional steel stress but the bond stress. For this reason no design should be attempted in structural Gypsum without giving careful consideration to bond—that is the summation of the perimeters of the reinforcing rods at any point must always be greater than the vertical shear at that point divided by 30 times $j-d$. In order to provide an additional factor of safety in this respect, a standard practice has been adopted of hooking all reinforcing rods.

Many beams and slabs of various spans up to 16 feet were designed according to the foregoing and tested. The following illustrations cover only a few of the tests but are typical of the general results and will suffice.

**Test of Beams.**

**Test Data of Plain Rectangular Beam.**
The above drawing represents a rectangular reinforced gypsum beam of short span which gave the following high strength results, failure being due to diagonal tension only.


Area of reinforcement. Sq. in. 1.22

Age of test—days 10

Load at first crack in pounds 23,980

Calculated steel stress at first crack in pounds per square inch. 29,200

Maximum load in pounds 23,980

)Vertical shear 146
)

Calculated stresses at )Horizontal shear 187
)

maximum load in pounds )Bond 191
)

)Tension 29,200
)

)Compression 1,580

Test Data of Two "T" Beams
The above drawing shows the details of two reinforced gypsum "T" beams of 16' - 0" span between points of support. These beams were identical except as to age. In these tests the rods were not turned or looped, and no provision was made for anchorage other than obtained from the bond of gypsum to the reinforcement. The following results were obtained:

Reinforcement, Corr. round. Straight 3(5/8") 3(5/8")

Area of reinforcement, Sq. in. 0.92 0.92

Age at test—days 20 20

Load at first crack in pounds 5.250 6.300

Observed steel stresses at first crack

in pounds per square inch 19,000 22,000

Maximum load in pounds 7,850 6,300

Stresses at ) Vertical Shear 87 70

Maximum load ( Bond 74 60

in pounds per ( Tension (calculated) 29,200 24,400

square inch ) Tension (observed) 28,600 22,300

Test Data on Five Reinforced Roof Slabs

The above represents the detail of five reinforced roof slabs which gave the following results:
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Clear Span</th>
<th>Load Applied</th>
<th>Load per sq. ft.</th>
<th>Dafl. inches</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9' 8&quot;</td>
<td>2200</td>
<td>200</td>
<td>.034</td>
<td>At these uniformly distributed loads.</td>
</tr>
<tr>
<td>2</td>
<td>9' 8&quot;</td>
<td>2400</td>
<td>218</td>
<td>.070</td>
<td>Formly distributed loads.</td>
</tr>
<tr>
<td>3</td>
<td>9' 8&quot;</td>
<td>2200</td>
<td>200</td>
<td>.034</td>
<td>Buted loads.</td>
</tr>
<tr>
<td>4</td>
<td>9' 8&quot;</td>
<td>2200</td>
<td>200</td>
<td>.034</td>
<td>There was no sign of failure.</td>
</tr>
<tr>
<td>5</td>
<td>9' 8&quot;</td>
<td>2400</td>
<td>218</td>
<td>.070</td>
<td></td>
</tr>
</tbody>
</table>

These reinforced roof slabs were designed to carry a uniformly distributed live load of 50 pounds with a safety factor of four. After the above tests the total loads were increased to 3,500 pounds, but other than the manifestation of horizontal shear cracks, there was no sign of failure.

The weight of these long span reinforced gypsum roof slabs is 17 pounds per square foot. When the effect of a continuous, rather than a beam ceiling is desired, the same slab can be made in an "H" section, viz., with a bottom flange similar to the top flange. A roof slab of this form weighs about 24 pounds per square foot, and has the same carrying capacity for live load.

Test of a 4½" x 1'-6" x 4'-0" Gypsum Roof Slab

- Span between supports 45-13/16". Weight 90.5#
- Weight per square foot nominal area 15.08#
Results of Bending test on 4'-0" Gypsum Roof Slab.

Load Applied at Center of Span.

<table>
<thead>
<tr>
<th>Load, Lbs.</th>
<th>Deflection, Inches</th>
<th>Equivalent Distributed Load Lbs. per Sq. Ft.</th>
<th>Remarks.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>.000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>.008</td>
<td>36.6</td>
<td></td>
</tr>
<tr>
<td>380</td>
<td>.031</td>
<td>126.8</td>
<td></td>
</tr>
<tr>
<td>440</td>
<td>.036</td>
<td>146.5</td>
<td></td>
</tr>
<tr>
<td>480</td>
<td>.039</td>
<td>160.0</td>
<td></td>
</tr>
<tr>
<td>520</td>
<td>.044</td>
<td>173.4</td>
<td></td>
</tr>
<tr>
<td>590</td>
<td>.050</td>
<td>196.8</td>
<td></td>
</tr>
<tr>
<td>640</td>
<td>.056</td>
<td>213.5</td>
<td></td>
</tr>
<tr>
<td>690</td>
<td>.061</td>
<td>229.8</td>
<td></td>
</tr>
<tr>
<td>720</td>
<td>.066</td>
<td>239.8</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td>.071</td>
<td>249.8</td>
<td></td>
</tr>
<tr>
<td>810</td>
<td>.075</td>
<td>269.8</td>
<td></td>
</tr>
<tr>
<td>850</td>
<td>.079</td>
<td>283.0</td>
<td></td>
</tr>
<tr>
<td>880</td>
<td>.085</td>
<td>293.0</td>
<td></td>
</tr>
<tr>
<td>920</td>
<td>.091</td>
<td>306.0</td>
<td></td>
</tr>
<tr>
<td>960</td>
<td>.096</td>
<td>319.5</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>.100</td>
<td>333.3</td>
<td></td>
</tr>
<tr>
<td>1040</td>
<td>.105</td>
<td>349.5</td>
<td>—Note: After 1-1/2 minutes the deflection was .110 and a small hair crack was visible in the bottom side of one rib, nearly under the load; after 12 minutes the deflection was .118, and both side ribs were cracked.</td>
</tr>
<tr>
<td>1080</td>
<td>.128</td>
<td>359.5</td>
<td></td>
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</table>

Load was now relieved, and a permanent deflection of .064 inch was observed. Slab was however intact, and apparently in as good condition.
Reinforced Gypsum Roof Tile

These results were so satisfactory that the United States Gypsum Company decided to put on the market a reinforced Gypsum roof tile of 4' span. This tile was 5" deep, 18" wide and 4' long. In order to get sufficient depth for stiffness and still maintain an economical section, it was decided to make a ribbed or joist tile as here shown:

Underside of 5" x 18" x 4'-0" Gypsum Roof Tile

This tile also met with success and it was but a short time before 5', 6' and now even 10' span (channel type) tile are made. The table on the following page gives dimensions, etc. of standard roof slabs as used today. They are designed for a live load of 50#/per square inch with a factor of safety of at least four.
### Schedule of Channel Type Roof Tile

<table>
<thead>
<tr>
<th>Length of Tile in Feet</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>2</td>
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</tr>
</tbody>
</table>

### Long Span Roof Tile - 18' Wide

- Reinforcing Bar: 4" x 3 1/2" Slot Width, 6" Cross Wires

### Longitudinal Section

- Plan: 18" Width, 40" Length

### Section A-A

- Section A-A: 2" Bar Tile

### Section B-B

- Section B-B: 4" Bar Tile

---

24" x 24" Bent

---

A7
The manufacture of reinforced Gypsum roof tile is quite a simple process. It is necessary merely to add water to the calcined Gypsum, stir for from thirty to sixty seconds and pour into a mould to set. In thirty or forty minutes it is sufficiently hard to remove from the moulds and attains almost full strength in a day's time. The tile are usually cast in the factory and shipped out when wanted. However, on account of the simplicity of the moulding equipment required, it is possible to cast them right at the building site. The standard equipment for manufacture consists of a series of moulds as here shown:
These moulds are arranged in series and are usually put under cover as shown in the following photograph:

![View of Field Moulding Plant.](image)

After the forms are assembled a bar support made of Gypsum is placed in the bottom of the form to support the reinforcing steel. After the reinforcing rods are placed a woven wire mat is laid in the top of the form. This can be clearly seen in the photograph of the Field Moulding Plant. The forms are then ready to receive the gypsum.

On small sized jobs the gypsum is mixed by hand in sheet-iron buckets, sixteen inches in diameter and twenty four inches in depth. As the material is received on the job in 100# sacks, enough water is placed in the bucket to set up 100# of gypsum of normal consistency. The sack of gypsum is then emptied into the bucket and stirred vigorously for from thirty to sixty seconds.
It is then poured into the molds and allowed to set, care being taken not to disturb the position of the reinforcing steel. As the material sets up and hardens the forms are dismantled, and the tile removed and carried off to cure. The forms are immediately cleaned and reassembled when they are ready to receive the next batch of gypsum.

The molds being arranged in series makes it possible to have the operation of molding the tile continuous, that is, while one set of forms are being poured, others are being cleaned, assembled, etc. In practice the average days run consists of 10 rounds or 10 complete cycles per form per day.

On large operations of over 100,000 square feet of roof area, it has been the custom to use a mechanical mixer. This consists merely of a revolving spindle that is let down into the same buckets as described above. A sketch of this mixer is given on the next page. Experiments have been tried with various types of concrete mixers, pug mills, etc, but all have proved unsatisfactory until the mixer shown on the following page, was hit upon.

The photographs shown on the following pages show typical installations of various kinds of gypsum roofs, namely solid slab, tee tile and channel tile.
8" Pulley

1/2" steel shaft.

7/8" Steel channel guides

1/4 20 Gauge hopper
In compiling this work the writers are greatly indebted to the United States Gypsum Company for furnishing photographs, and to Professor Willis Slater and Mr. C. Payne, who can justly be called the fathers of Structural Gypsum.
UNDER SIDE OF A TYPICAL GYPSUM ROOF DECK

ROOF SLABS IN PLACE READY FOR GROUT TO BE POURED IN JOINTS
GYPSUM LONG SPAN ROOF TILE SPANING FROM
PURLIN TO PURLIN.

GYPSUM LONG SPAN ROOF TILE SPANING FROM
TRUSS TO TRUSS
ERECTION OF 10 FT. SPAN "T" TYPE ROOF TILE

EXTERIOR VIEW
GYPSUM ROOF TILE CAN BE LAID AS SOON AS STEEL IS IN PLACE

TYPICAL MONITOR ROOF CONSTRUCTION

NOTE LIGHTNESS OF STEEL CONSTRUCTION AND LIGHT REFLECTIVE QUALITIES OF TILE
4" HOLLOW REINFORCED GYPSUM ROOF TILE
THEIR LOW CONDUCTIVITY PREVENTS
CONDENSATION IN EXTREME CONDITIONS
AND PROVIDES MAXIMUM HEAT INSULATION

GYPSUM USED FOR DRAINAGE
A SUBSTITUTE FOR CINDER CONCRETE
LIGHT IN WEIGHT AND SETS IN THREE HOURS
3" SOLID REINFORCED GYPSUM ROOF TILE

MAKES A GOOD BASE ON WHICH TO NAIL

LUDOWICI OR BAKED CLAY TILE

3" SOLID REINFORCED GYPSUM ROOF TILE

LAID ON TYPICAL SAW TOOTH CONSTRUCTION