Presentation at ACI 2016 Fall Conference

Owner Participation in Innovative Engineering Solutions

By

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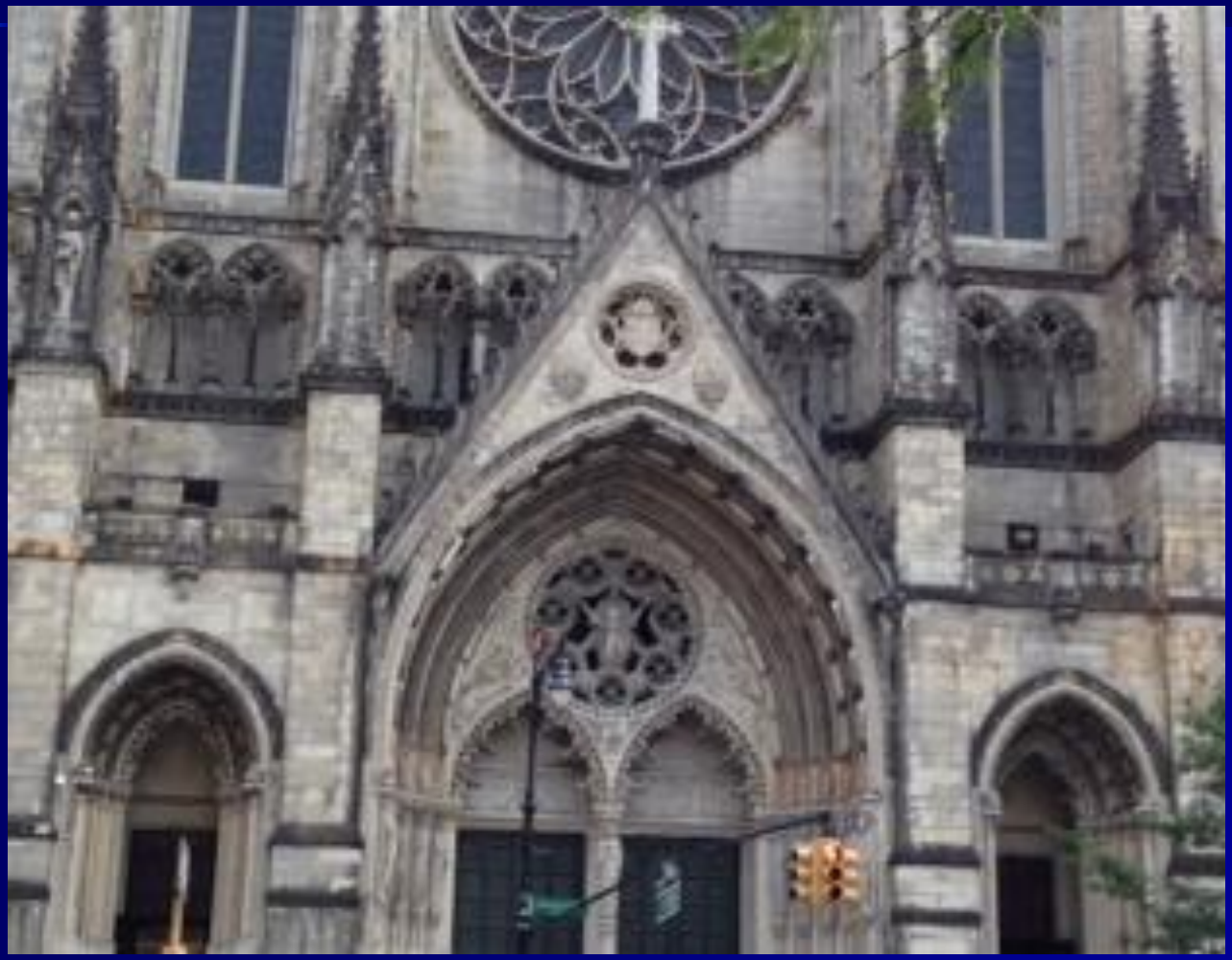
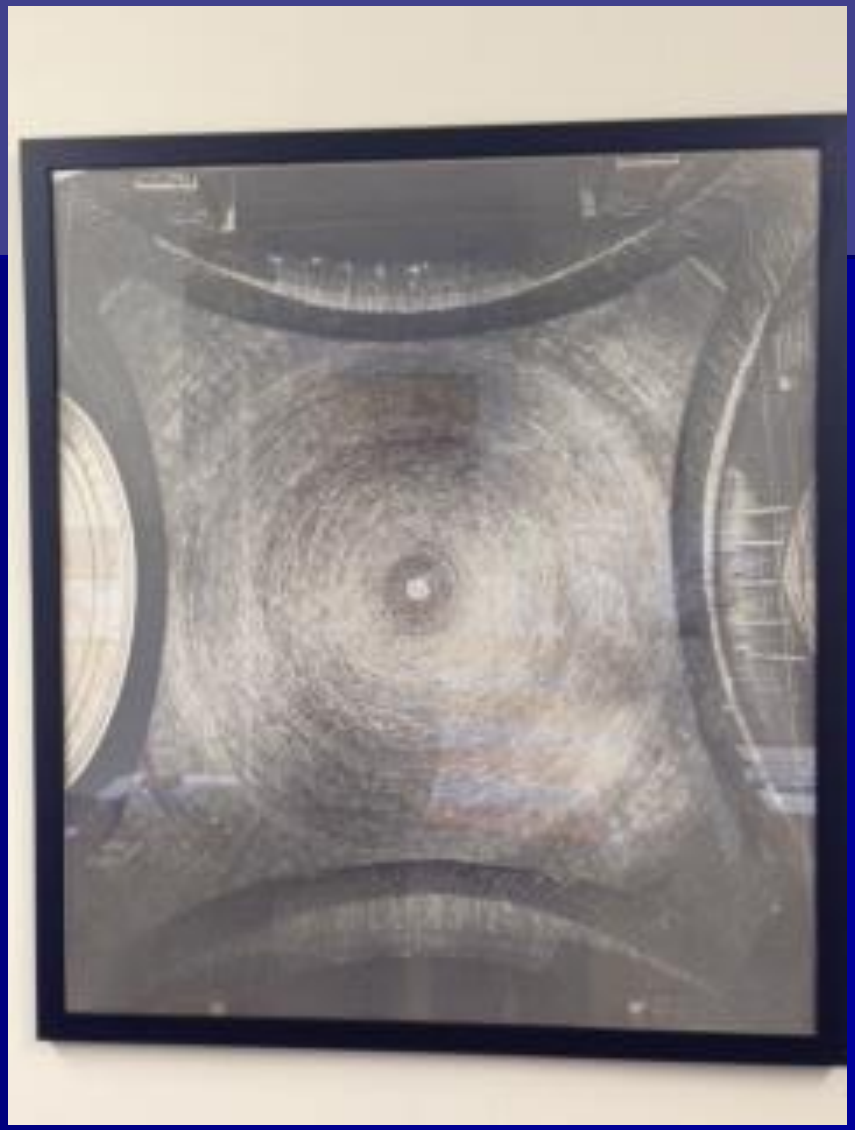
Invisible Innovations, Inc.

Structural Investigation of Dome at the Cathedral of St. John the Devine





RAFAEL GUASTAVINO

Sr 1842 – 1908 Jr. 1872 - 1950

Guastavino Sr. (1842-1908) (left) and Rafael Guastavino Jr. (1872-
llection, Avery Library)

Guastavino Team

- Gustavino Sr. educated as Architect and Engineer in Barcelona in 1860s.
- The same professor who would later teach Antoni Gaudi
- Moved to US in 1881
- His first major project, Boston Public Library in 1889
- Guastavino Jr. had no formal education, but built some of the most daring masonry structures in history.
- He supervised the construction of 70-foot span tapered church dome in 1895 at the age of 23. Tapers from 6 inches at support to 4 inches at crown. Span-to-thickness ratio of about 200.
- Built in 9 weeks, self-supporting thru construction with minimal formwork to guide geometry.

Guastavino Masonry Shells

- Uses ceramic tiles 6x12x1 Inch
- Much less material than stone vaulting, lesser thickness (4 inches), less self- weight and horizontal thrust
- Lesser thickness also attributed to double-curvature of the shell allowing multiple to supports compressive load paths
- Tiles joined with plaster of Paris, quick setting time eliminating need for support from below
- Also building out from a wall in successive arcs allows for minimal or no form work
- Provides inherent fire resistance

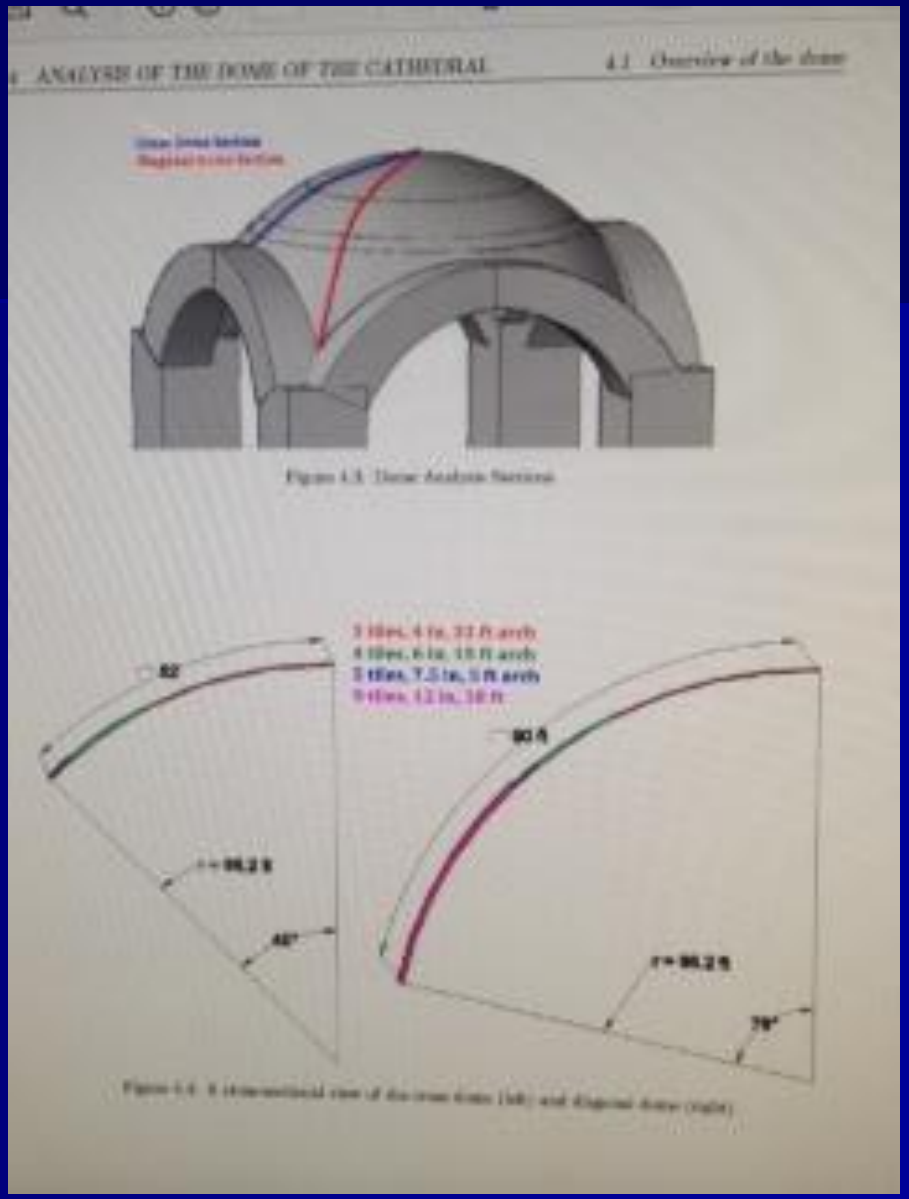
Guastavino's Major Projects in US

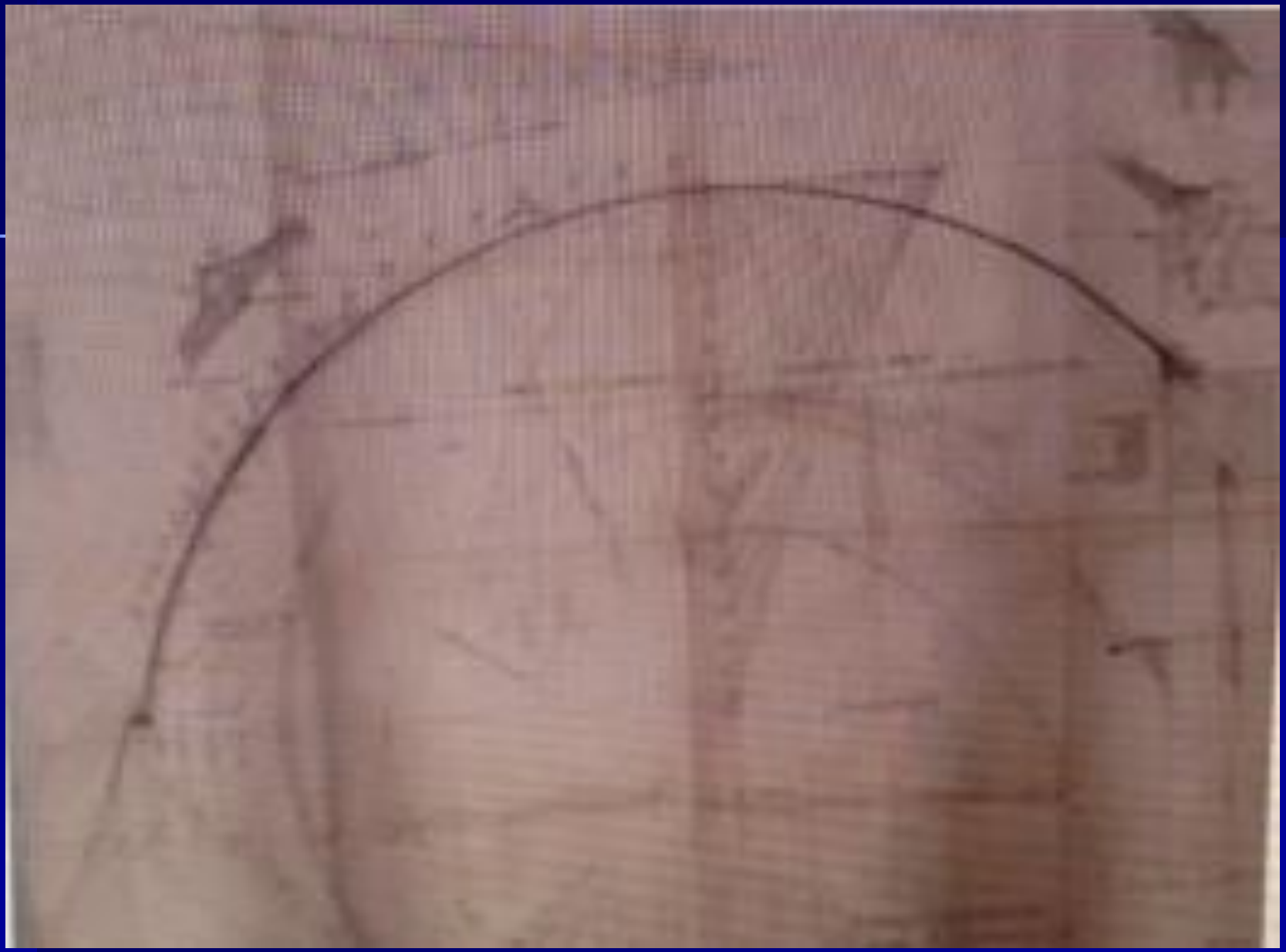
- Riverside Church, NY
- St. Thomas Church, NY
- Church of the Heavenly Rest, NY
- Boston Public Library
- Grace University Church
- Nebraska State Capitol
- Smithsonian Museum , Washington, DC
- Girard Trust Co. Building, Philadelphia

Over 600 existing projects in 40 US states active and functioning

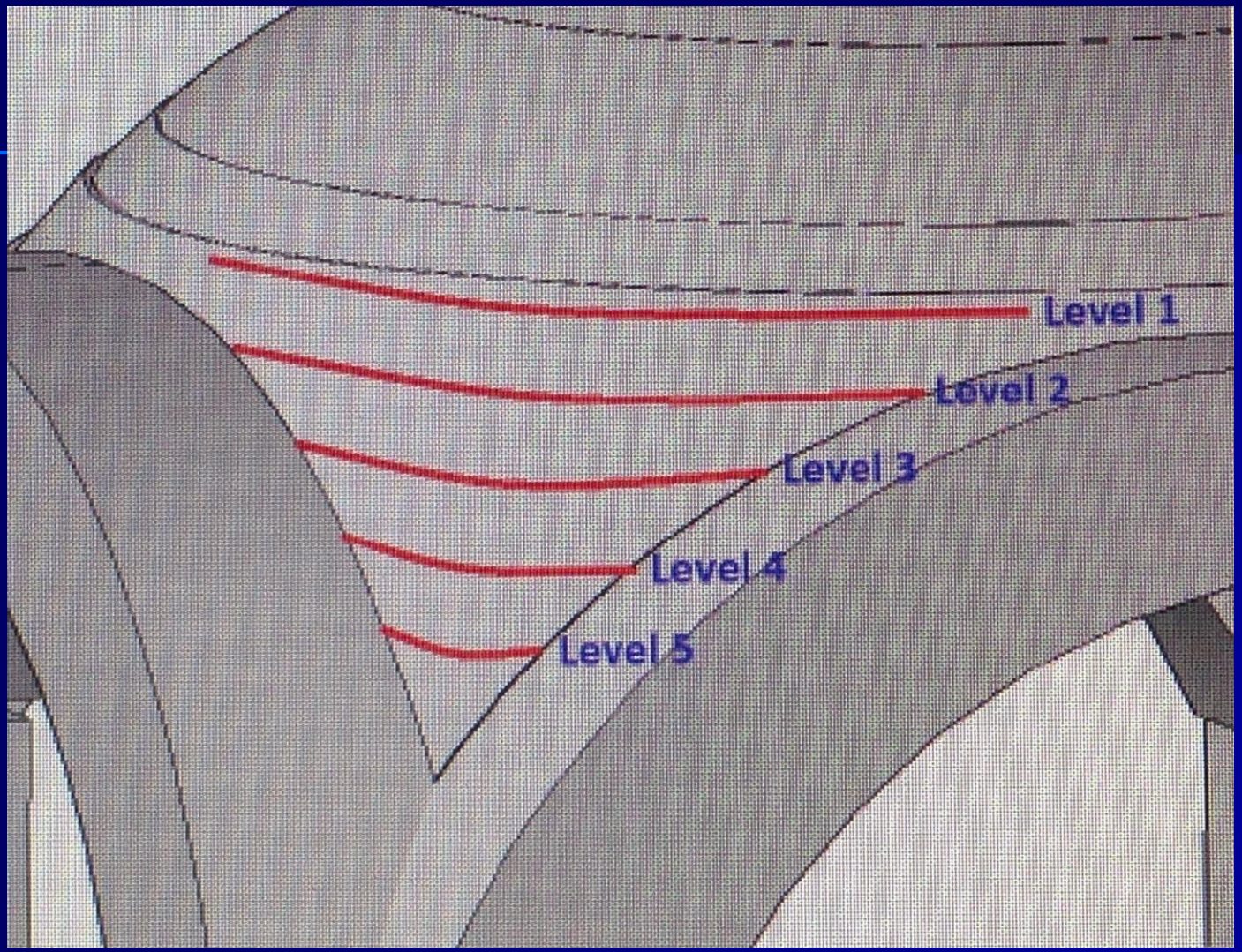
Dome Design

- A temporary structure designed and built to temporarily cover the large exposed crossing area.
- Guaranteed for 10 year life.
- 135 foot span
- 155 feet from ground
- 4 inch thick at Crown
- 12 inch thick at supports
- Built using only cables to guide the tile placement.
- Masons were supported on concentric rings of tiles as construction cantilevered out into space.
- Completed in 15 weeks 1909





Steel Reiforcing at all corners



Contract Page 1

The said party of the Second Part hereby agrees for the construction of the floor of the crossing, the four pendentives over the crossing, a temporary roof dome over the crossing springing from the pendentives and coating the great arches, over that portion where the roof is to be applied with cement at the Cathedral of St. John the Divine.

The work will be fairly complete on or before July 1, 1909. The said party of the first part agrees to pay the said party of the second part a sum of $35,100.00

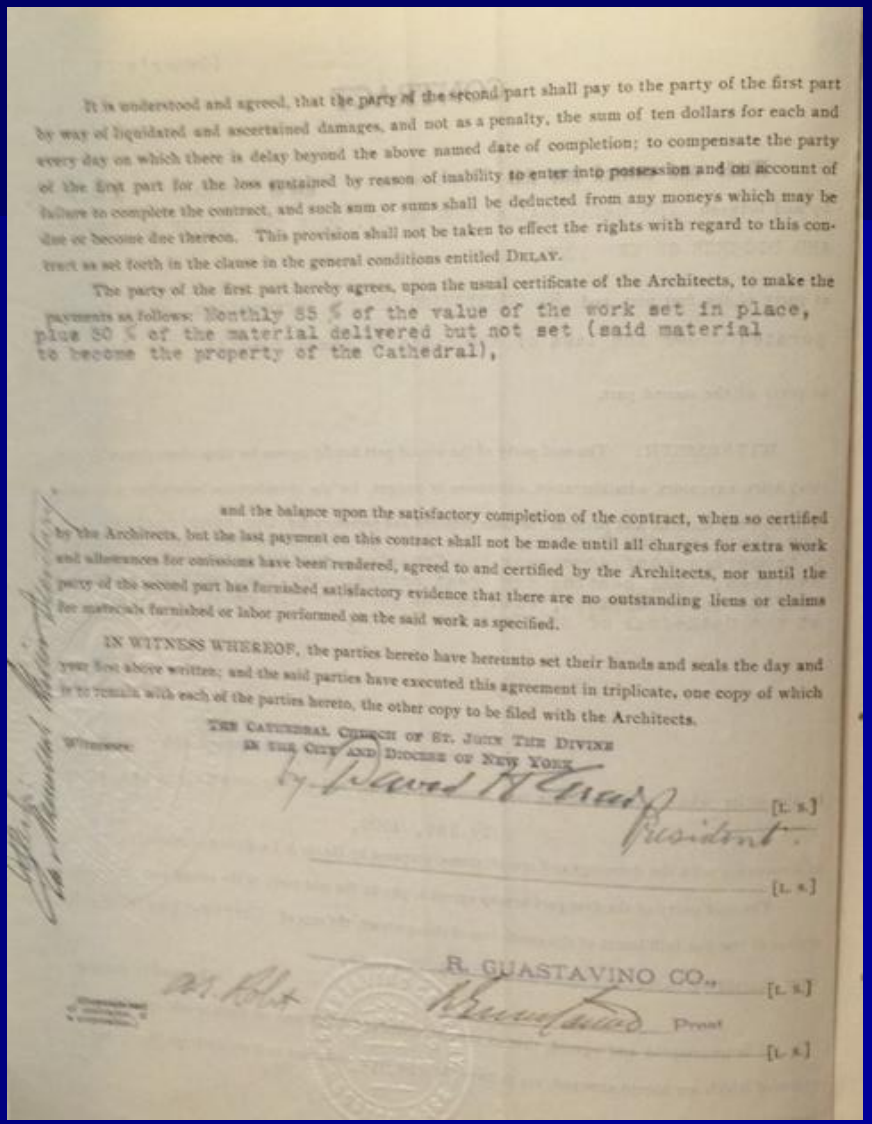
CONTRACT

ACI 2016/Shroff

Contract Page 2

It is understood and agreed , that the part of the second part shall pay to the part of the first part by way of liquidated and ascertained damages, and not as a penalty the sum of $10/day for each day beyond above date of completion…..

The party of the first part hereby agrees, upon the usual certificate of the Architects, to make the payments as follows: Monthly 85% of the value of the work set in place, plus 50% of the material delivered but not set (said material to become the property of the Cathedral).



It is understood and agreed, that the party of the second part shall pay to the party of the first part by way of liquidated and ascertained damages, and not as a penalty, the sum of ten dollars for each and every day on which there is delay beyond the above named date of completion; to compensate the party of the first part for the loss sustained by reason of inability to enter into possession and on account of failure to complete the contract, and such sum or sums shall be deducted from any moneys which may be due or become due thereon. This provision shall not be taken to effect the rights with regard to this contract as set forth in the clause in the general conditions entitled DELAY.

The party of the first part hereby agrees, upon the usual certificate of the Architects, to make the payments as follows: Monthly 85 % of the value of the work set in place, plus 50 % of the material delivered but not set (said material to become the property of the Cathedral),

and the balance upon the satisfactory completion of the contract, when so certified by the Architects, but the last payment on this contract shall not be made until all charges for extra work and allowances for omissions have been rendered, agreed to and certified by the Architects, nor until the party of the second part has furnished satisfactory evidence that there are no outstanding liens or claims for materials furnished or labor performed on the said work as specified.

IN WITNESS WHEREOF, the parties hereto have hereunto set their hands and seals the day and year first above written; and the said parties have executed this agreement in triplicate, one copy of which is to remain with each of the parties hereto, the other copy to be filed with the Architects.

THE CATHEDRAL CHURCH OF ST. JOHN THE DIVINE
IN THE CITY AND DIOCESE OF NEW YORK

Witnesses:

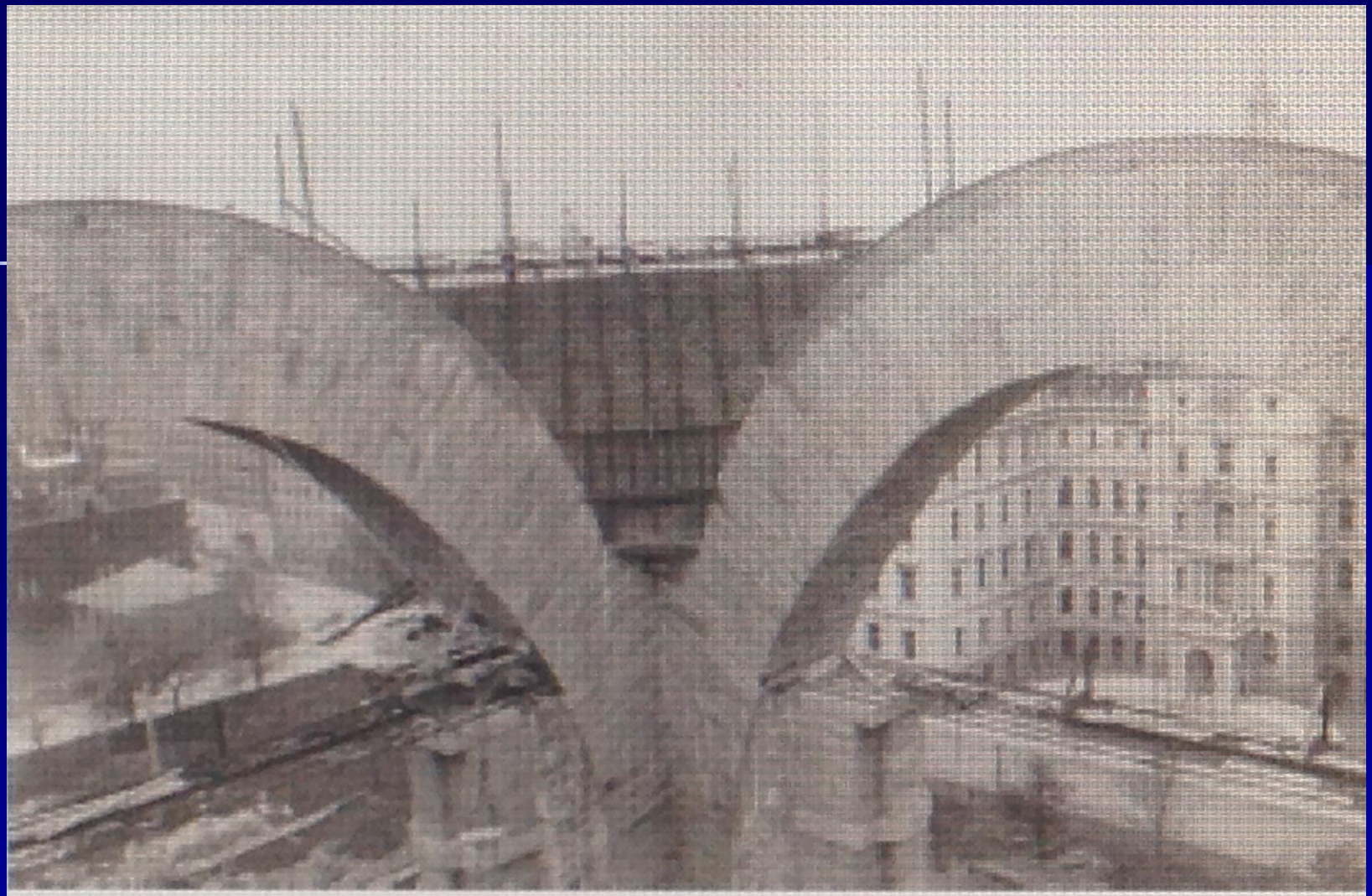
by David H. Greer President [L. S.]

[L. S.]

R. GUASTAVINO CO., [L. S.]

Pres't

[L. S.]



igure 1.5: Pendentives of the dome under construction

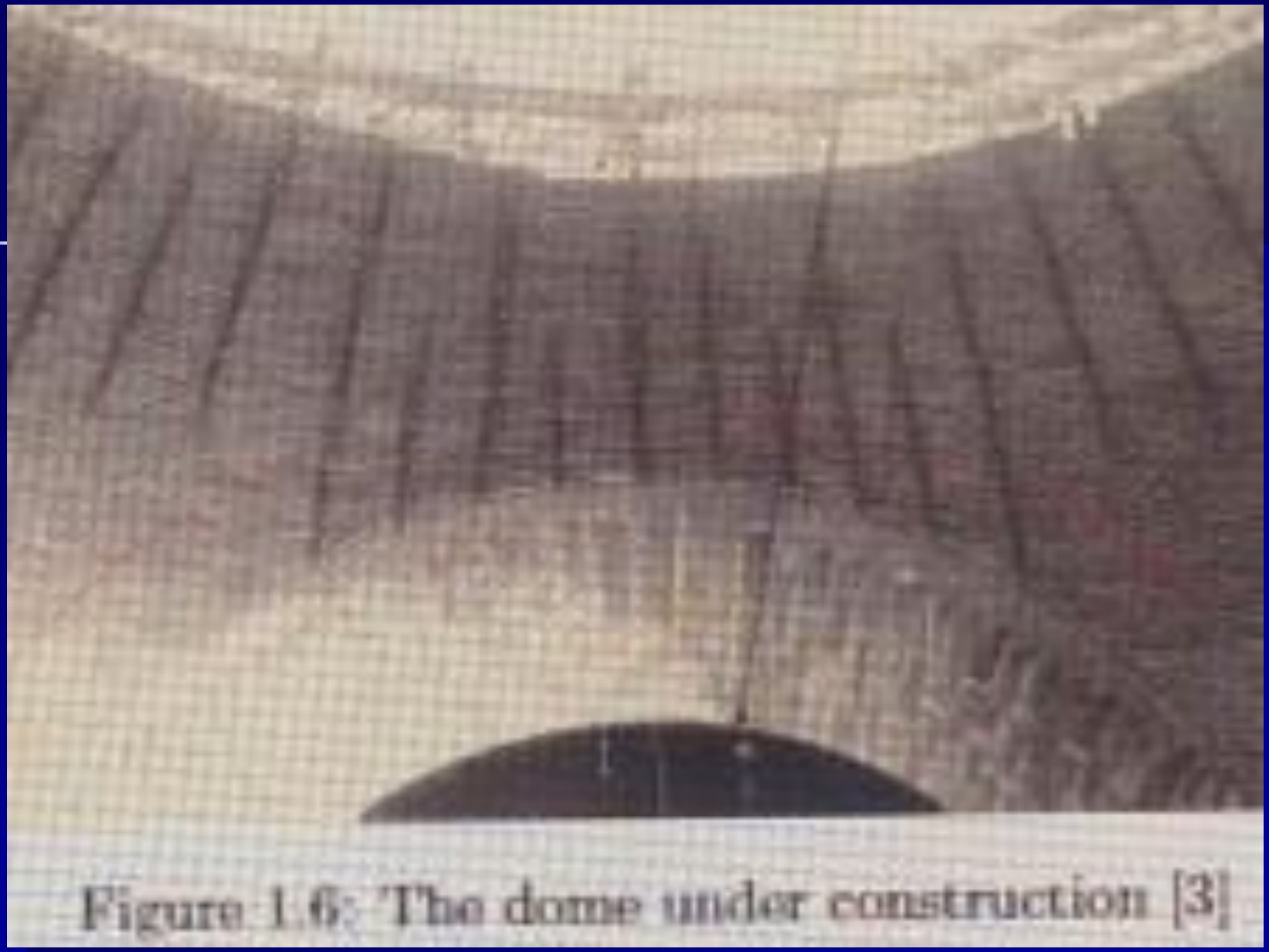


Figure 1.6: The dome under construction [3]

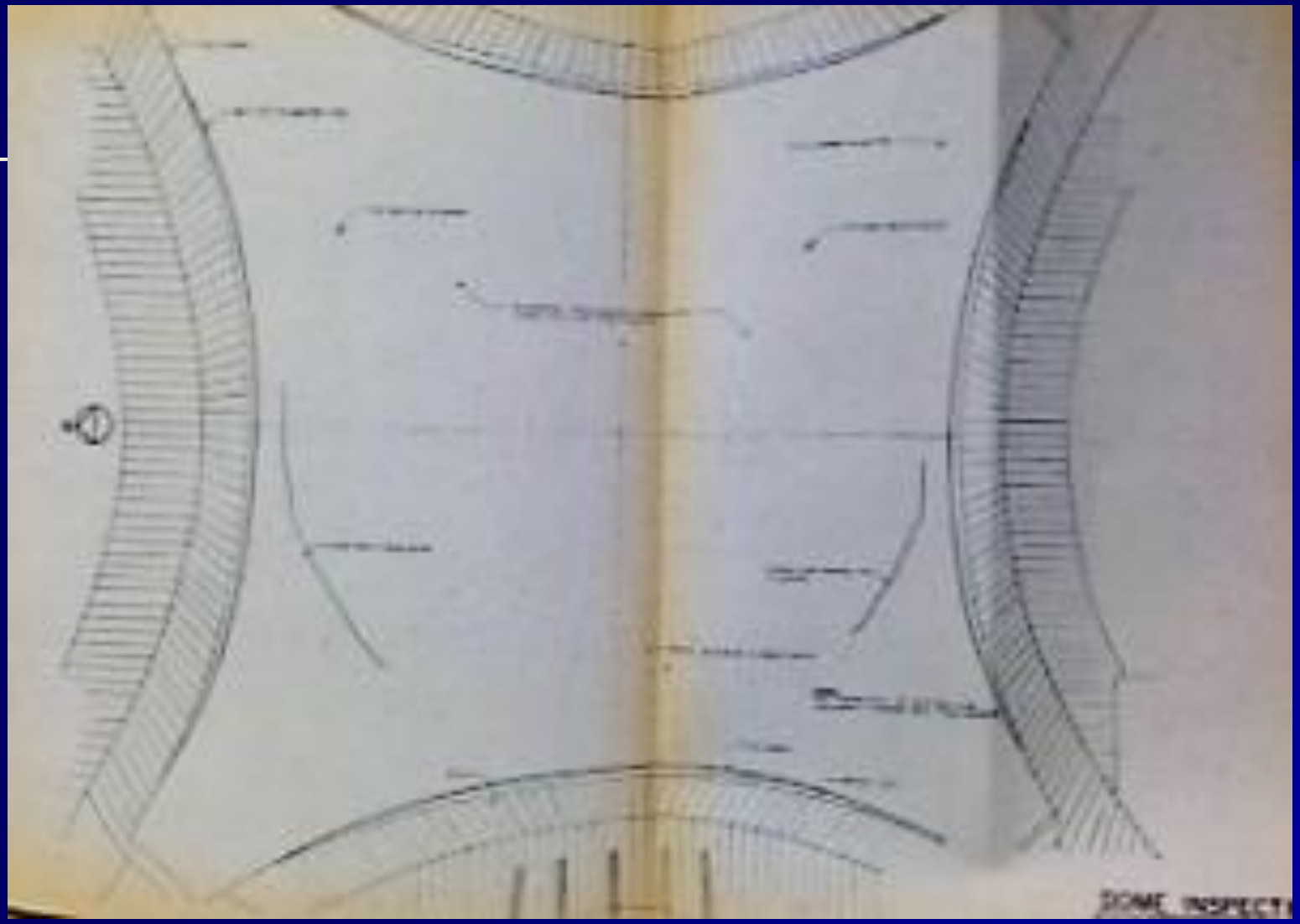
Purpose of Investigation

In 1969, pieces of mortar and tile dropped to the floor of the crossing. This evidence of apparent structural distress and previous history of cracking led to concern regarding the integrity of the dome.

Prager Kavanagh Waterbury was retained to

- investigate the existing condition of the dome
- Evaluate its structural adequacy, and
- Provide recommendations and repair procedures

Dome Inspection – Ceiling Plan



Brief Repair History of the dome

- 1917 repairs following an investigation of cracks on outer face
- 1937 repairs included addition of a continuous reinforcing ring at the pendetives after inspection revealed additional cracks in that area. Guastavino company suggested construction of permanent tower and removal of the dome.
- 1943 roofing was removed, old cracks re-grouted and new roofing installed. Use of insulation was considered but not adopted. The replacement of the dome was discussed but no agreement between parties involved.

Brief Repair History of the dome

- 1956 structural evaluation indicated the dome was structurally sound despite the fact that tile chips were found on floor.
- 1960 dome was reroofed. Water intrusion damage observed in SW corner.
- 1961, prof. Fitch from Columbia suggested dome be replaced.

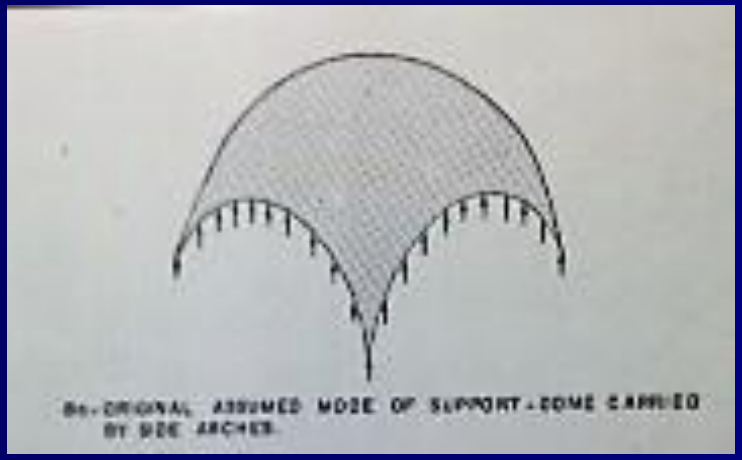
Lading Conditions

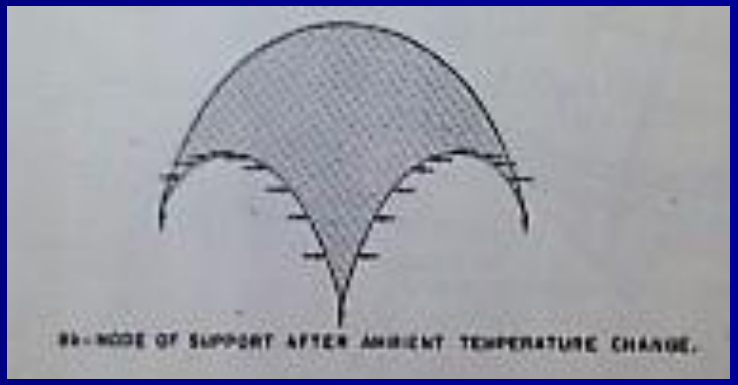
(1) Assumed Continuous support on all 4 sides

- Temperature Static
- Temperature raised 30^0 F
- Temperature lowered 70^0 F

(2) Assumed support only at corner pendentives

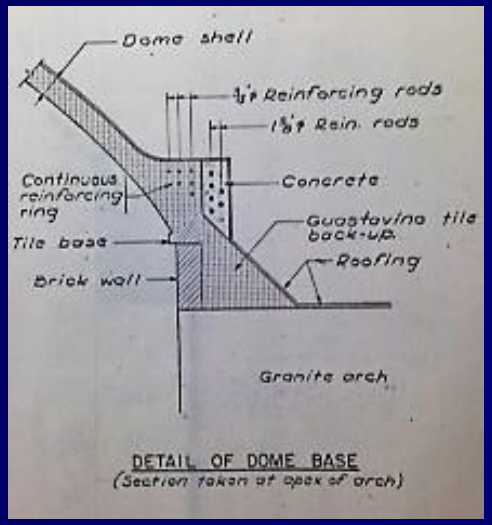
- Temperature Static
- Temperature raised 30^0 F



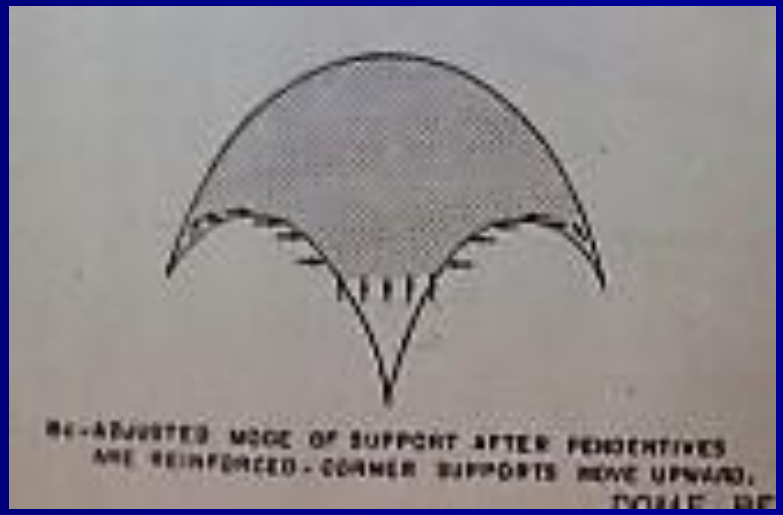


Original Assumed mode of Support dome carried by side arches

Mode of support after ambient temp. change

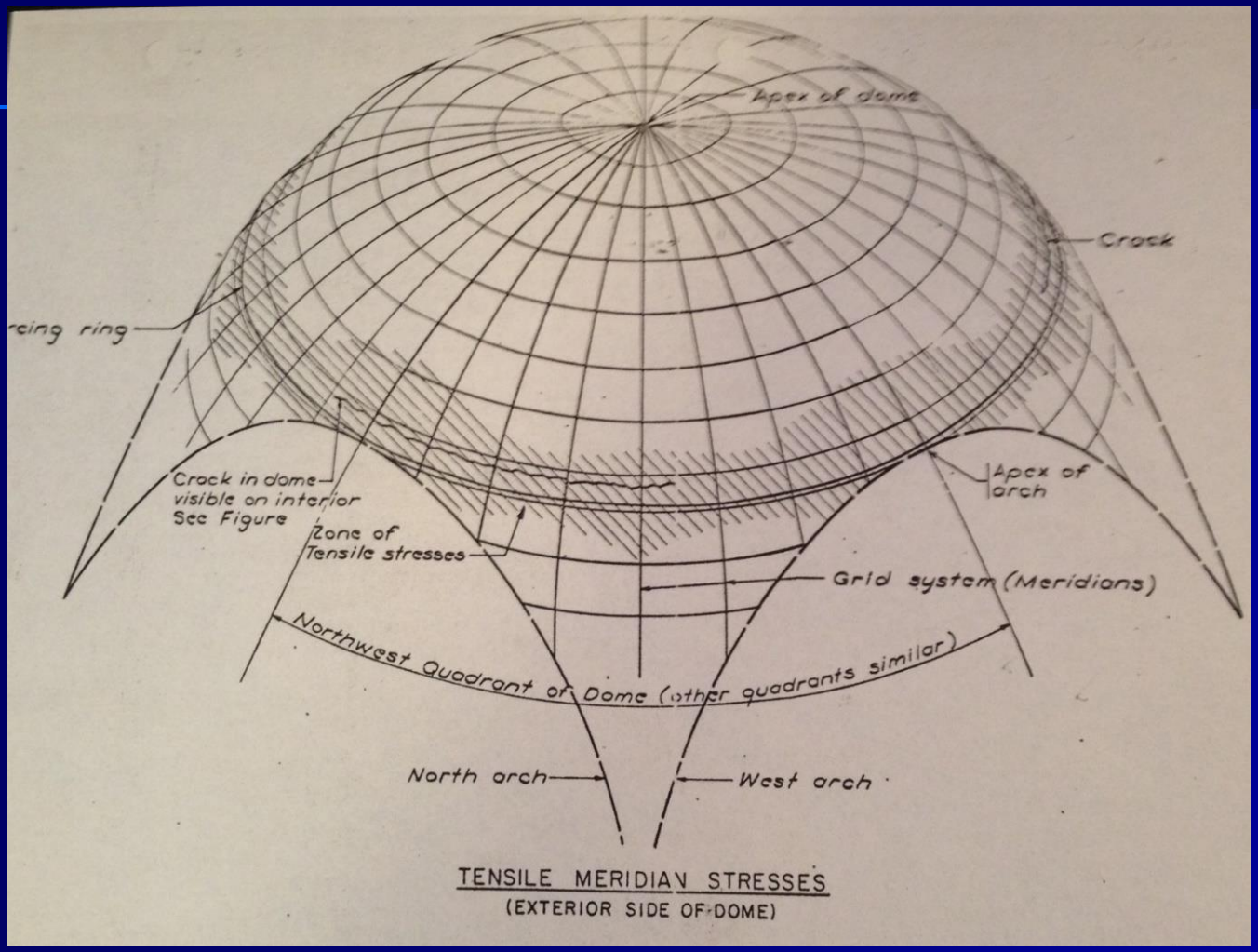


Addition of a Continuous Reinforcing Ring in 1937

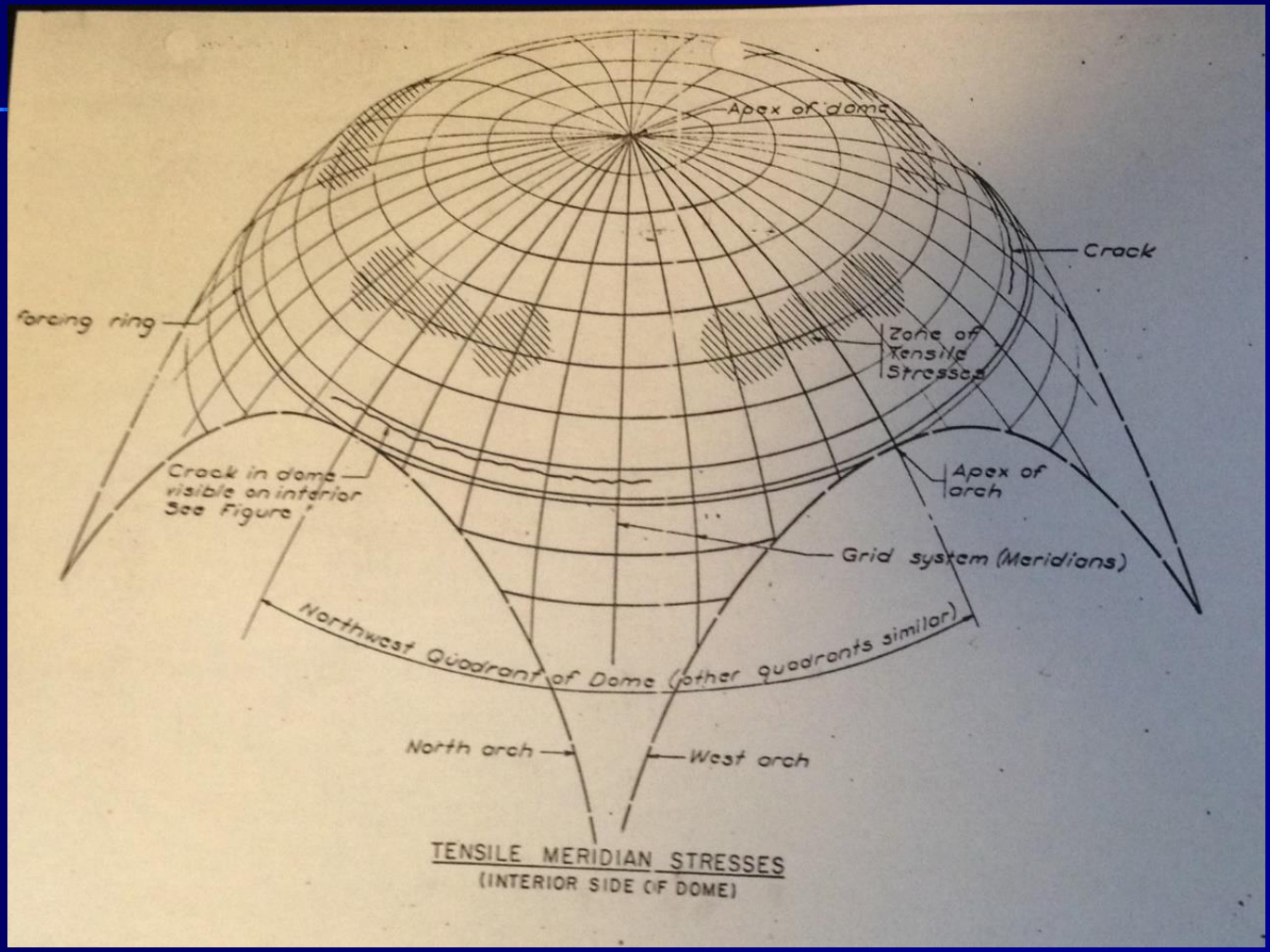


Adjusted mode of support after pendetives are reinforced – corner supports move upwards

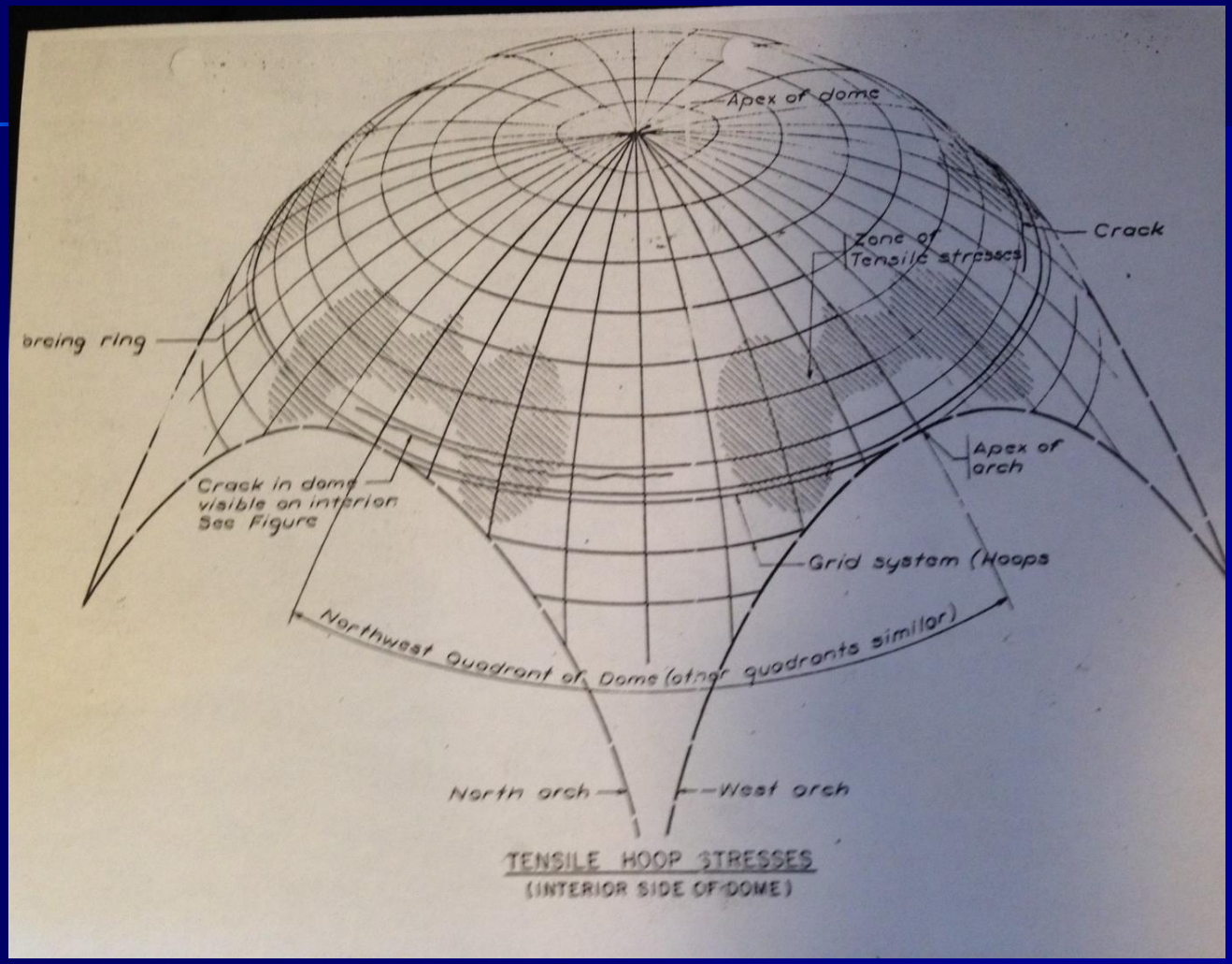
Tensile Meridian Stress - Exterior Side of Dome



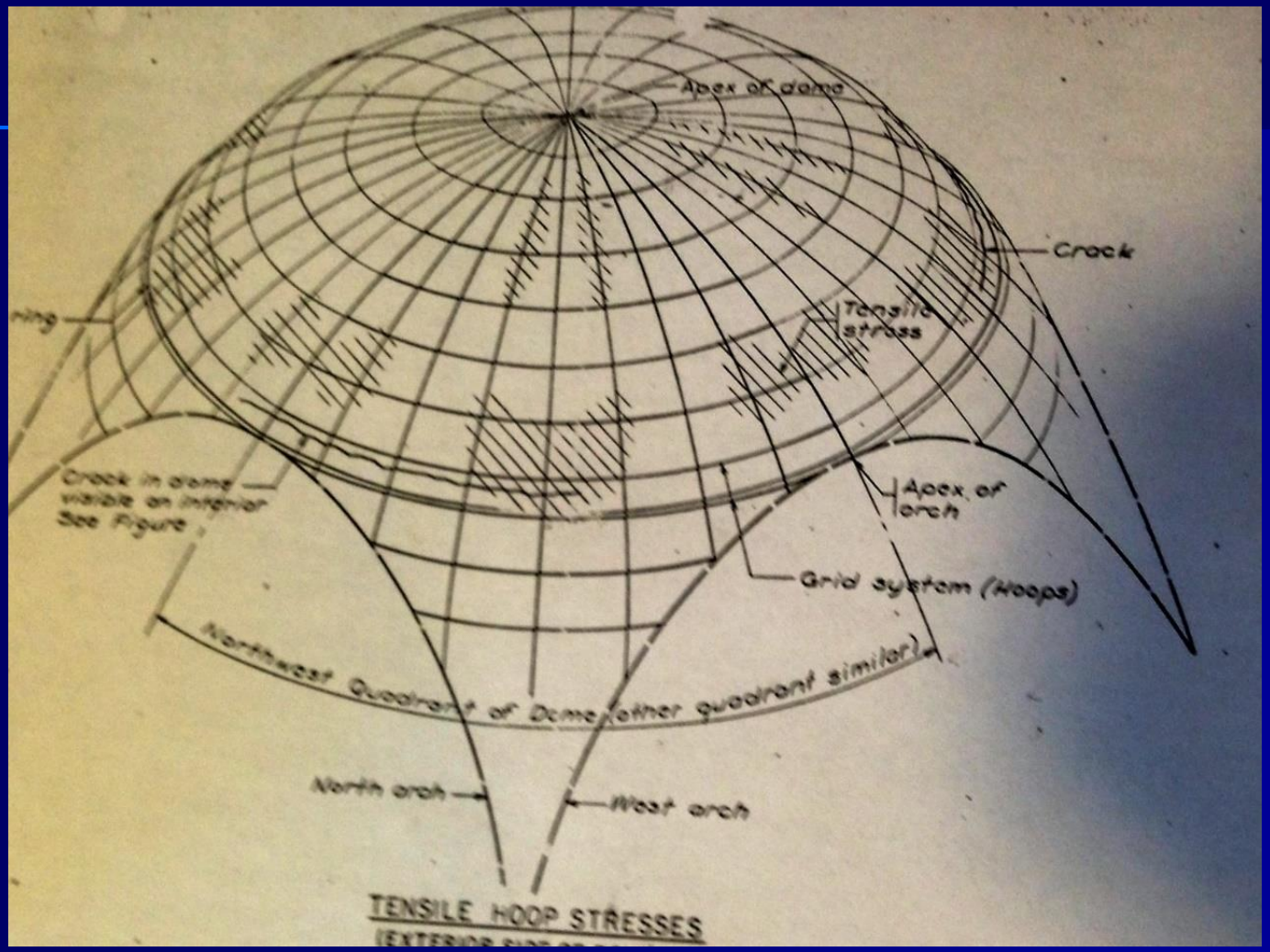
Tensile Meridian Stress - Interior Side of Dome



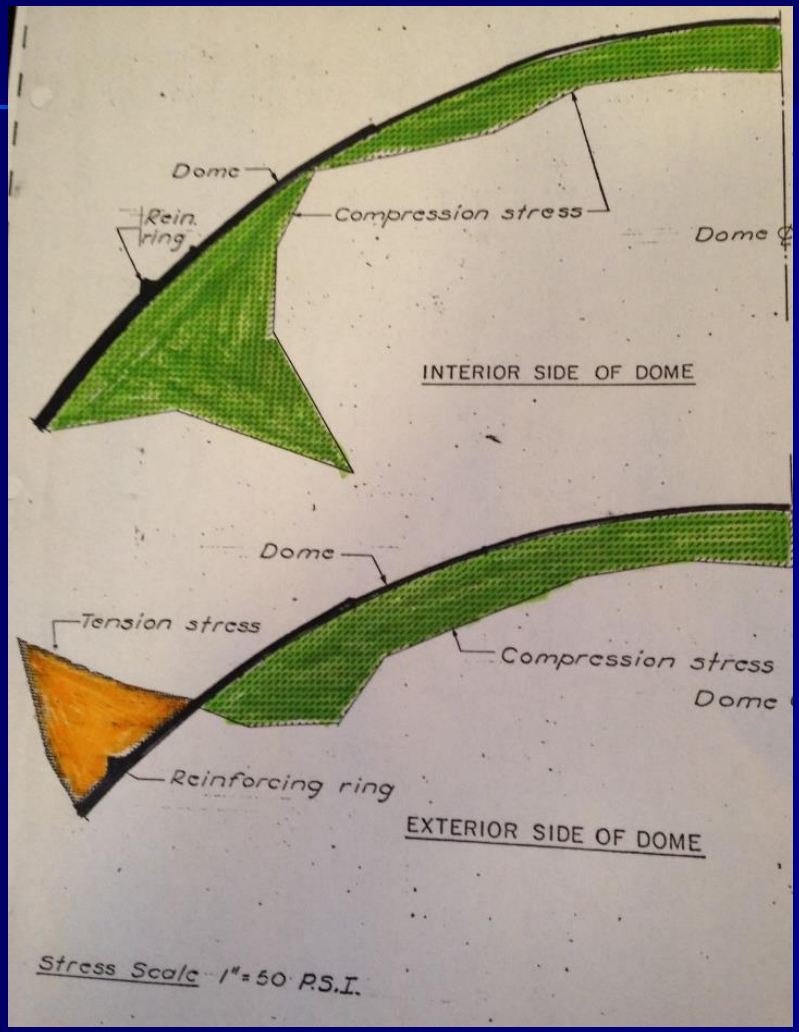
Tensile Hoop Stress - Exterior Side of Dome



Tensile hoop Stress - Interior Side of Dome



Meridian Stress



Interior Side of Dome

Exterior Side of Dome

Conclusions and Recommendations

- Though no sign of imminent failure of the dome, the effects of temperature variations and the moisture intrusions over the years have caused distress and will progressively worsen.
- If periodic temperature variations are eliminated, the structural adequacy of the dome can be assured for many years. This can be accomplished by providing thermal insulation on the exterior surface of the dome and new roofing.
- Provide netting at underside of dome to prevent danger of large pieces of mortar or tile falling to the floor.
- The repair recommendations included removal of existing roofing, inspection and repair of the dome outer surface, providing insulation over the entire dome outer surface and installing membrane waterproofing and providing scaffolding at the underside of the dome to repair the dome underside and arches and to install the netting.

Repair work at Night