Construcción de una
BOVEDA ONDULADA

Parte Experimental del Trabajo de Seminario de Edificación del alumno Sr. NATALIO DAVIDOVICH:

CUBIERTAS ONDULADAS DE HORMIGON SISTEMA CTESIPHON

Los trabajos mencionados en esta Sección han sido desarrollados por alumnos de la Escuela de Arquitectura y, en general, corresponden a la parte práctica de la Cátedra de Seminario de Edificación ubicada en el 6º año de estudios.

Al INSTITUTO DE EDIFICACION le cabe, en estos casos, revisar el programa de la experiencia, calificar su verdadero objetivo, limitar su alcance al tiempo compatible con el desarrollo de los trabajos de Seminario y facilitar a los alumnos los medios técnicos de ejecución y control.

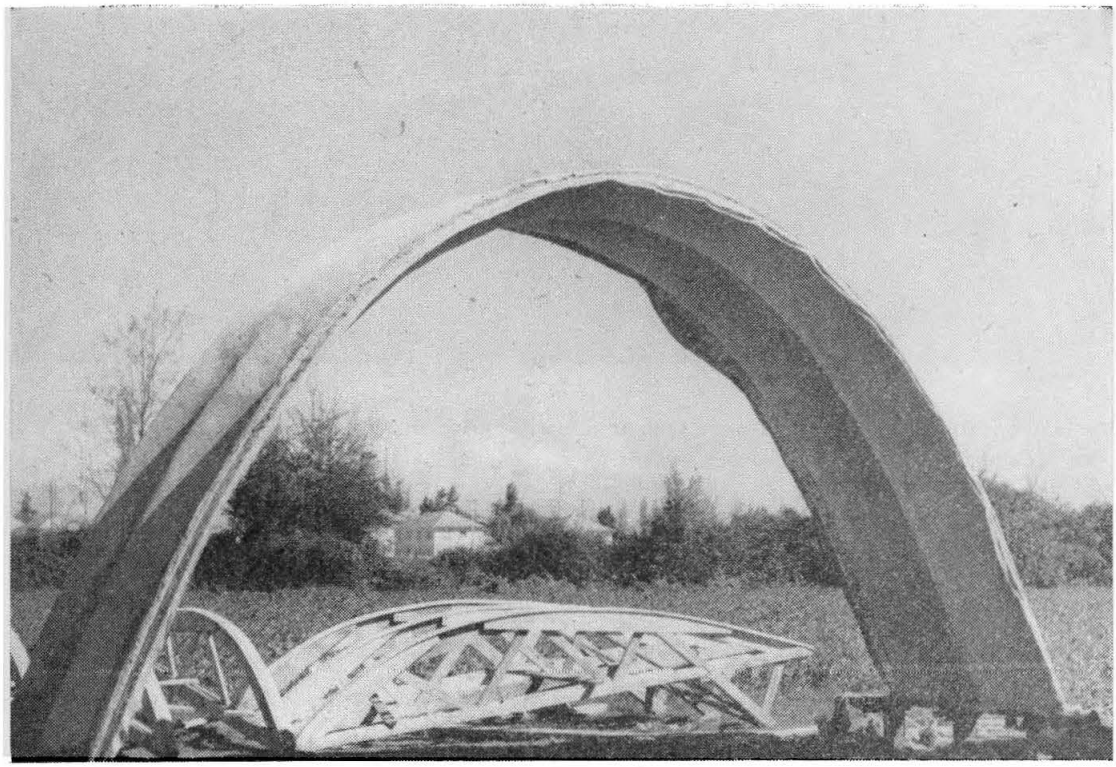
Presentación.

El trabajo de Seminario al cual pertenece la experiencia que se relata, aborda el estudio de estructuras laminares de doble curvatura en que las directrices son curvas catenarias.

El estudio está basado en el método constructivo denominado CTESIPHON (palabra que conmemora una notable bóveda persa, ejecutada hace 1.600 años a orillas del río Tigris, cerca de la ciudad de Bagdad), ampliamente difundido por sus promotores y que cuenta con importantes realizaciones en Inglaterra, España, India, etc.

El creciente interés mundial de los arquitectos por las formas laminares no ha encontrado eco aún en la arquitectura nacional, entrabado, seguramente, por el temor muy justificado de afrontar nuevas técnicas con los medioevales procedimientos constructivos de que se dispone.

La presente experiencia se refiere, en especial, a una nueva técnica de encofrados para láminas de doble curvatura, continuas y simétricas. Por su sencillez y bajo costo, es en sí revolucionario frente a los encofrados convencionales y despertará —seguramente— gran interés entre arquitectos y constructores. Aun cuando la presente experiencia se refiere a una bóveda relativamente pequeña para esta clase de estructuras, con el sistema que aquí se preconiza se han construido cubiertas de 30 y más mts. de luz y con espesores menores a 10 cm.



Definición de la estructura.

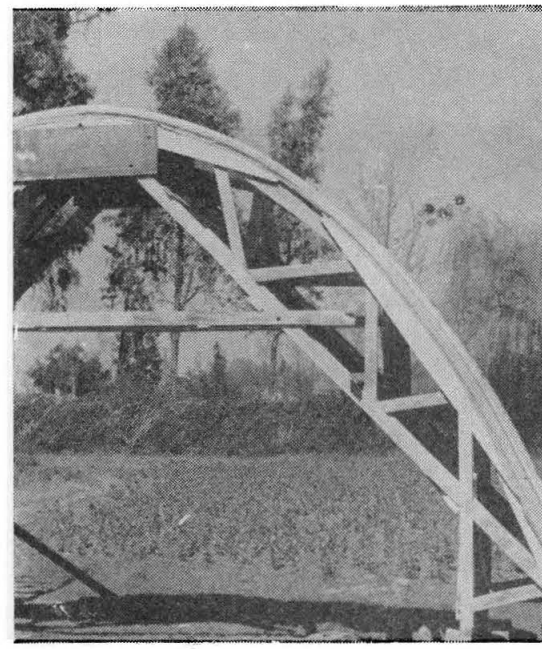
Se trata de una bóveda de cañón (profundidad indefinida) ondulada en el sentido longitudinal. La directriz transversal es una catenaria invertida. Las ondulaciones son catenarias normales, redondeadas en las crestas.

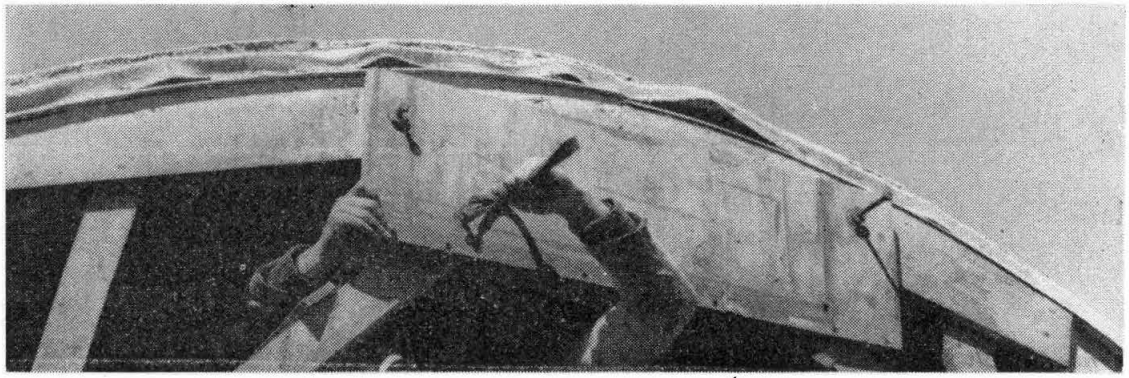
Bajo la acción del peso propio del material que las constituye, no hay esfuerzos de flexión y aquél será equilibrado a través de compresiones crecientes de la clave hacia los apoyos. Dado el peralte de la forma adoptada, el empuje tiene valores insignificantes y puede ser fácilmente absorbido por el terreno de fundación.

Las sobrecargas horizontales o verticales dispuestas arbitrariamente, provocarán flexiones en la estructura y para contrarrestarlas, será necesario la lámina. El material utilizado es naturalmente hormigón, en masa y armado según las exigencias impuestas. Utilizando armadura y colocando en obra el mortero mediante presión de aire pueden conseguirse notables reducciones del espesor de la lámina.

Encofrado.

El sistema de encofrados consta de arco formeros, articulados en los arranques y en la clave, desarmables, cuyo trasdós obedece al trazado de la curva catenaria determinada por el cálculo. En el caso de esta experiencia, dichos arcos se ejecutaron de tablas elaboradas, colocados a 0,90 m. entre ejes, apoyados sobre cuñas para facilitar el descimbramiento.





El espacio entre los arcos se cubrió con arpillera ordinaria del tipo de 12 onzas por m². La tela fue colocada sin tensión especial, clavada con grapas a los arcos, y está destinada a recibir directamente el hormigón. Bajo su peso, la arpillera tomará una curva que es una catenaria entre dos arcos formeros. Obsérvese que la curvatura es variable de la clave a los arranques, en razón a la variación de la componente vertical del peso propio. En otras palabras, la curvatura de la arpillera será máxima en la clave de la estructura laminar y casi nula en los arranques.

Según la magnitud de la bóveda, distancia entre los arcos formeros, espesor y peso del material, deberá elegirse el tipo y robustez de la arpillera. Por lo general, el desprendimiento de la tela después del fraguado se realiza con facilidad pudiendo ser usado varias veces.

Hormigón.

En esta primera experiencia no se hizo un estudio especial para la preparación del hormigón, el que queda definido mejor como un mortero con arena gruesa, atendiendo a las características siguientes reunidas por los materiales.

Arido único, módulo de fineza =	3,90	
Primer tamiz que retiene, el de	19,1	mm.
Porcentaje de huecos	33	%
Peso específico	2,67	
Peso específico aparente . . .	1,70	"
Residuo más fino que tamiz 200	3,2	%

Este árido contenía en todo caso, un 31% de granos de tamaño superior a 4,76 mm.

El mortero fue preparado con 1 parte de cemento "Super Melón", 3 partes de la arena descrita y 200 litros de agua, la que sufrió variaciones por las necesidades artesanales.

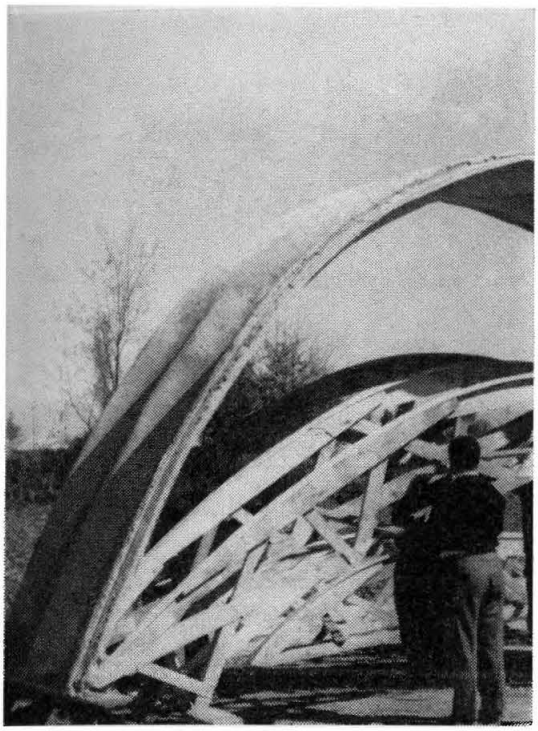
Los ensayes de ruptura a compresión arrojaron los siguientes resultados, sobre probetas cúbicas de 7 cm. de arista:

19 Kg/cm² a las 24 horas
70 Kg/cm² a las 48 horas
240 Kg/cm² a los 8 días

Ejecución de la lámina.

El trabajo de la primera etapa fue enteramente manual, colaborando en él dos albañiles sin experiencia anterior en esta clase de trabajos y un ayudante de albañil.

Se comenzó por rigidizar la arpillera mediante una capa delgada de mortero preparado con arena fina, lanzado con la plana, sin enrasar.



El material se adhirió a la arpillera en excelentes condiciones. A las 24 horas se colocó una segunda capa de 2 cm. de espesor, utilizando en ésta y en la siguiente, el hormigón cuya descripción se hizo en (4). La tercera capa se colocó 48 horas después de la primera. La superficie (extradós) de la bóveda se terminó platachando el material con llana de madera hasta obtener la textura de "grano perdido".

Curado.

Se tomaron precauciones de curado regando la lámina 2 veces al día durante 10 y protegiéndole de la deshidratación y las heladas.

Descimbrado.

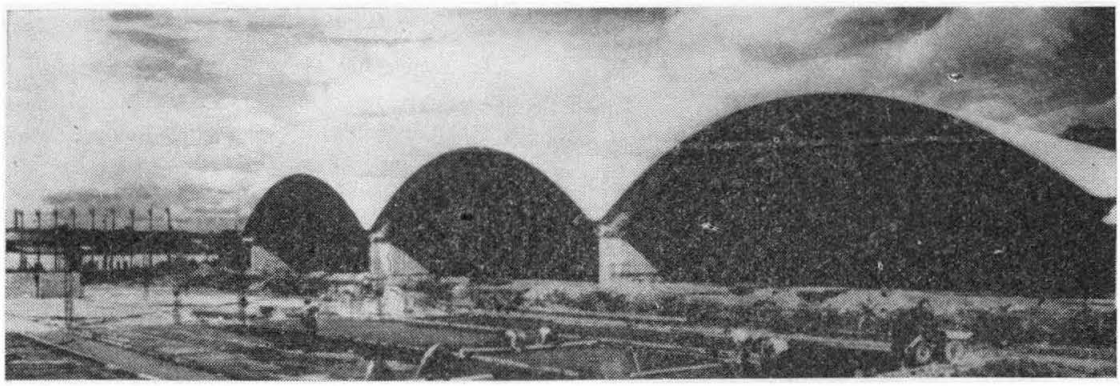
Se llevó a cabo a los 8 días, aun cuando el resultado de los ensayos habría permitido hacerlo a las 48 horas. Primero se aflojaron las cuñas; posteriormente, el dispositivo de articulación de la clave, lo que consintió un descimbrado sin dificultad alguna. Los arcos formeros pueden utilizarse indefinidamente por cuanto la limpieza de las operaciones de desencofrado que se lleva a cabo sin violencia mecánica asegura una larga duración al material y a las juntas clavadas.

Observaciones a la primera etapa.

La estructura tiene un aspecto elegante como puede apreciarse en las fotografías que ilustran este texto y aún cuando no tiene armadura, no presenta grietas en el extradós; esto puede interpretarse como que no fue afectada por la retracción de fragua, que no han aparecido tracciones (lo que era de esperarse) y que la dilatación térmica ha sido absorbida por la flexibilidad del conjunto.

Presenta —en cambio— corrugaciones y anchas grietas localizadas en el intradós que se produjeron indudablemente durante el proceso de acomodación del material sobre la arpillera y *antes del endurecimiento del hormigón.*

Estas grietas pueden explicarse teniendo en cuenta que el mortero fue arrojado sobre un encofrado semielástico en capas sucesivas. La primera capa (de resistencia nula por su escaso espesor) curvó parcialmente a la arpille-



Fábrica de whisky en Paysley, Escocia. Arq. Lothian Barclay. Arco triple de 6 cm. de espesor y 30 metros de luz de cada arco

ra sin agotar en absoluto su capacidad total de deformación. La curvatura se acentuó con la aplicación de la segunda capa (más pesada) y llegó a su límite cuando aplicada la tercera capa, se completó el peso propio total del conjunto. La segunda capa sufrió corrugaciones y grietas durante el proceso de su colocación, pero era suficientemente resistente, a pesar de sus grietas, para permitir a la tercera capa su acomodación sobre un medio rígido.

Estas grietas deben evitarse a toda costa estudiando más a fondo el verdadero comportamiento mecánico de la arpillera bajo la tensión producida por el hormigón fresco y usando una primera capa de tal espesor que ella sola sea capaz de producir la deformación máxima.

Programa de la segunda etapa.

a) Experiencias parciales para fijar la flecha máxima tolerable en la arpillera. Estudio más acucioso de diversas telas susceptibles de ser usadas como encofrado.
b) Uso de aditivos para mejorar la trabajabilidad y disminuir la dosis de agua hasta un asentamiento de 7 cm., lo que, combinado con un acelerador de fragua, permita un desencofrado a las 24 horas.
c) Hormigonado de la lámina mediante aire comprimido. Estudio de la velocidad óptima del chorro, presión de trabajo y rendimiento.
d) Armadura eventual de la lámina con malla cuadriculada de alambre.
e) Costos y tiempos de operación.

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