Thin-shell concrete structures: problems in identification and attribution

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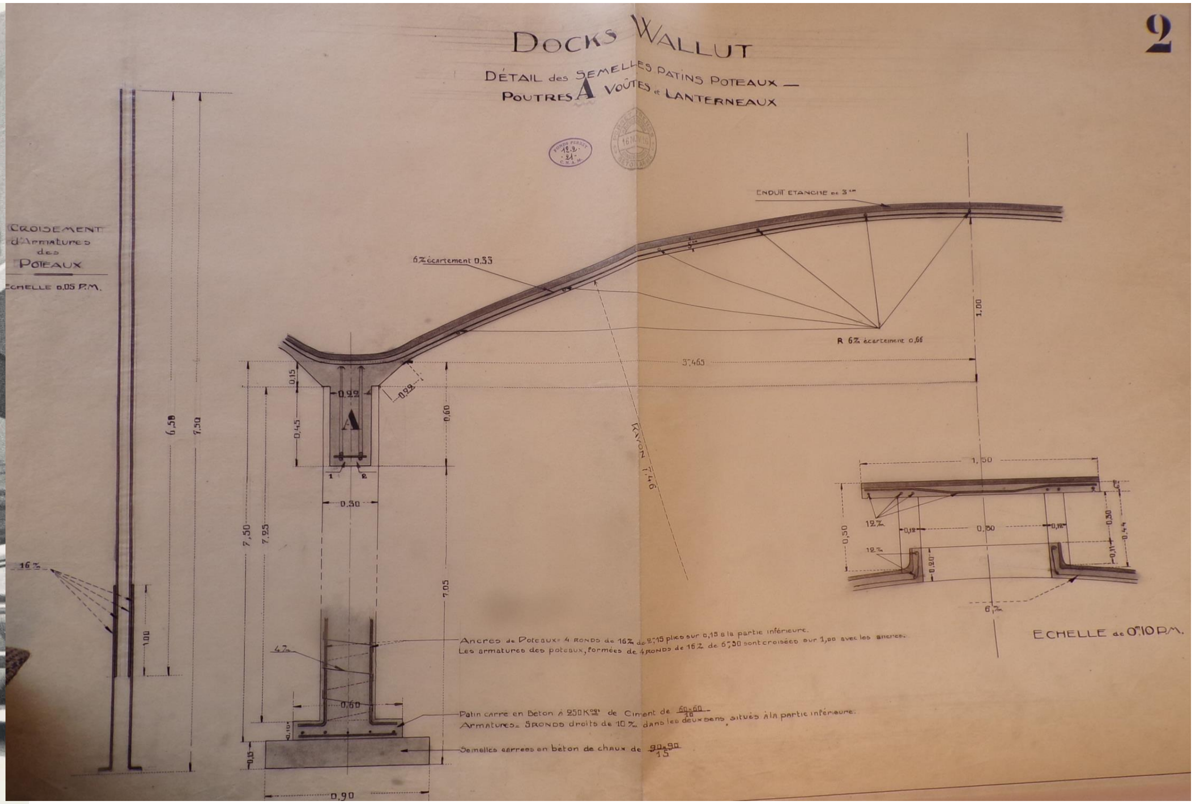
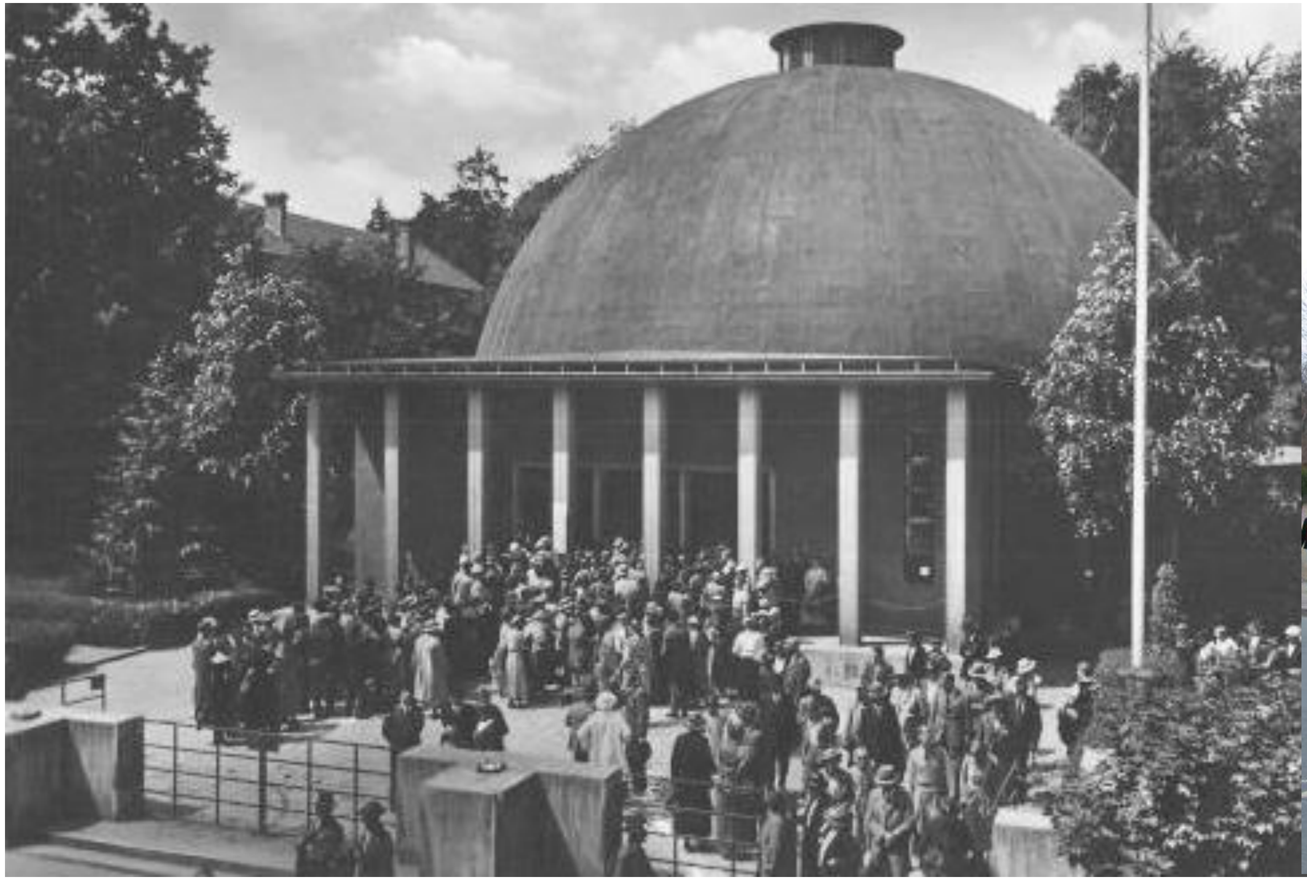


‘First thin-shell structure in the world’



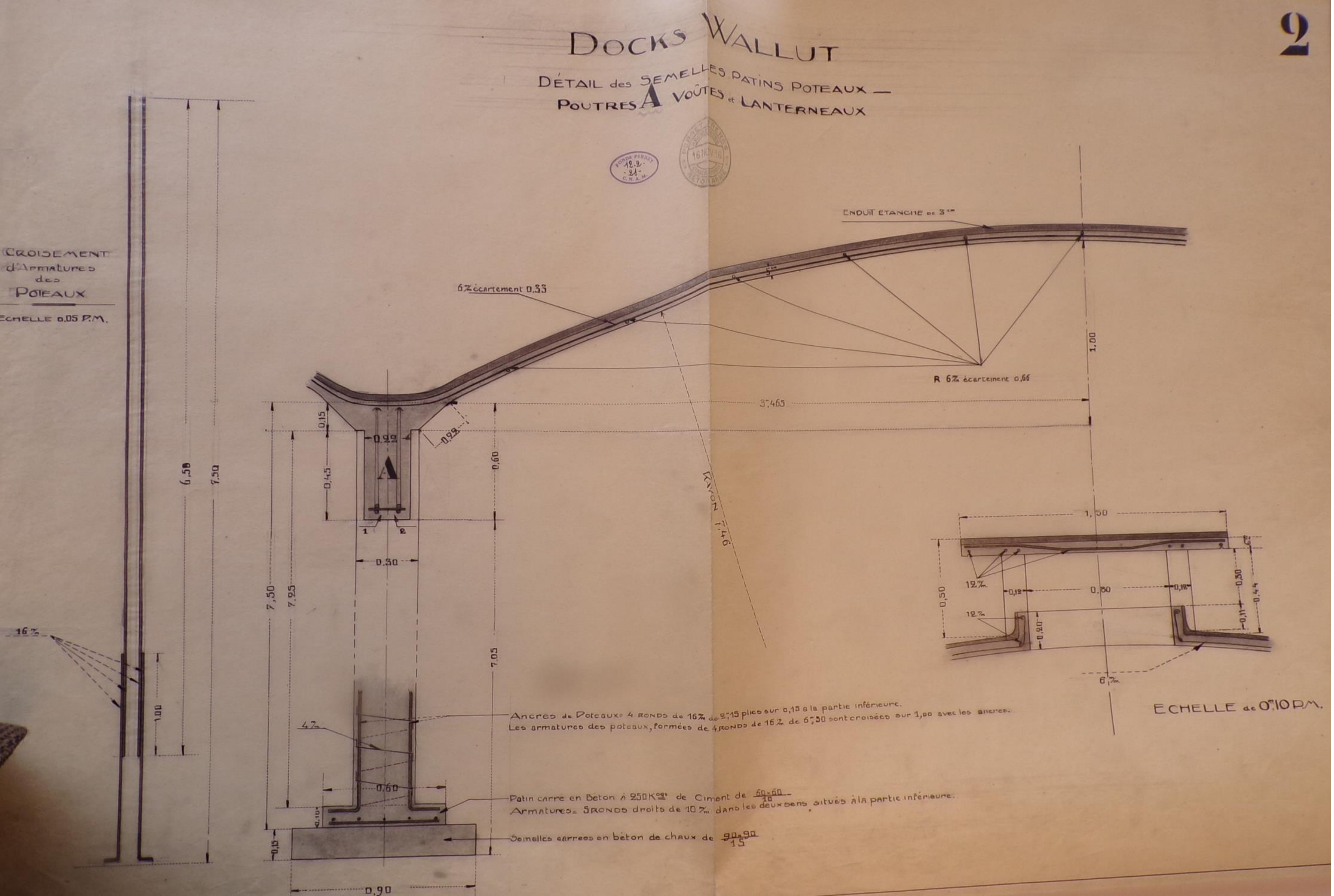
Zeiss Planetarium, Jena, 1926

Wikimedia Commons, Carlos-12commonswiki, creator

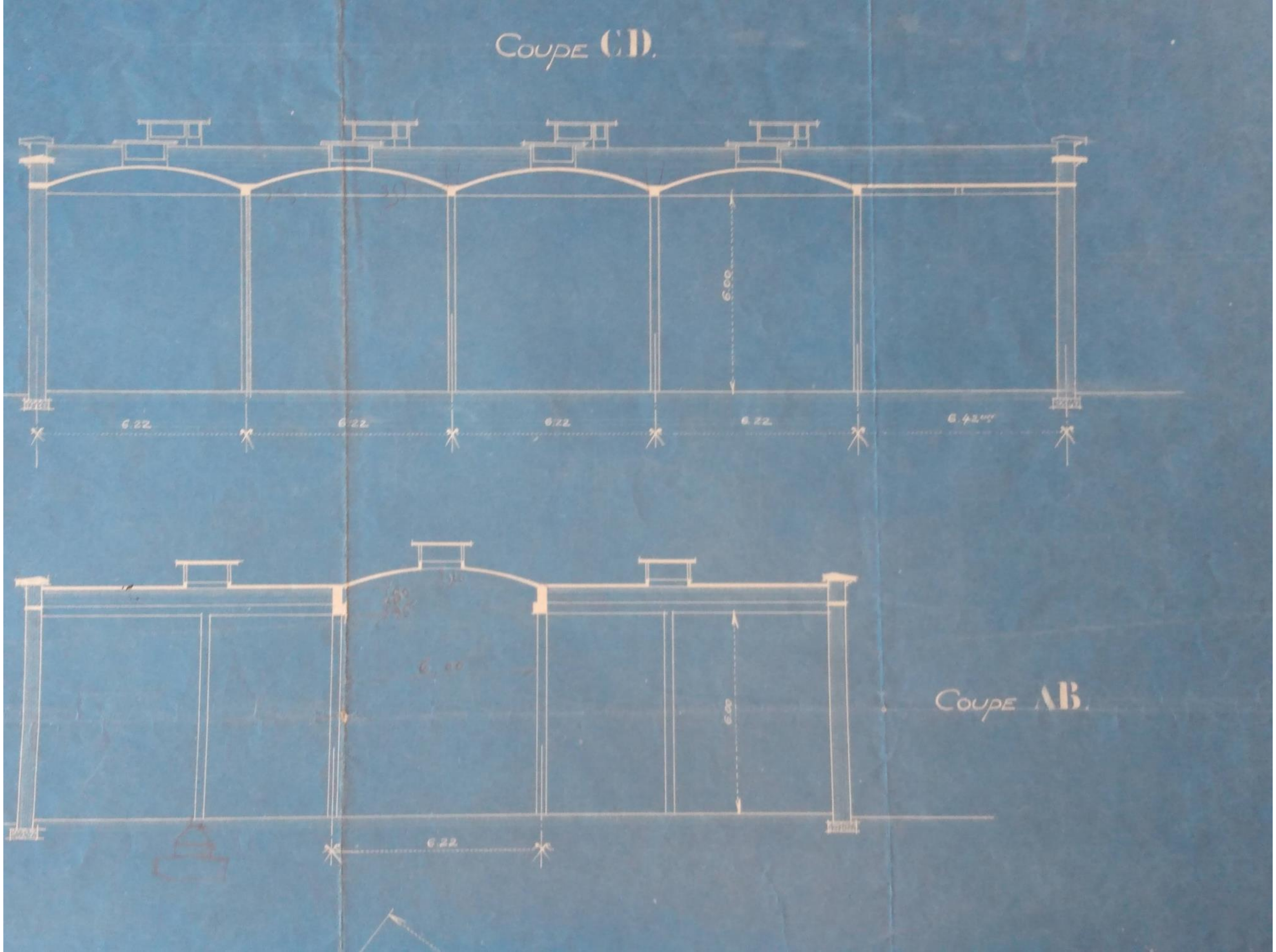
Photo by Charlene Roise

‘Later, in 1925, Bauersfeld, Dyckerhoff, and Widmann A.G. designed the shell for the planetarium in Jena, the first thin reinforced concrete shell structure in the world.’ Krivoshapko, Bock Hyeng, and Mamieva (2014)

‘Finsterwalder worked on the mathematical theory of barrel shells until he published the first workable formulations in 1933. Again the form came from the formulas.’ Billington, The Tower and the Bridge (1983)

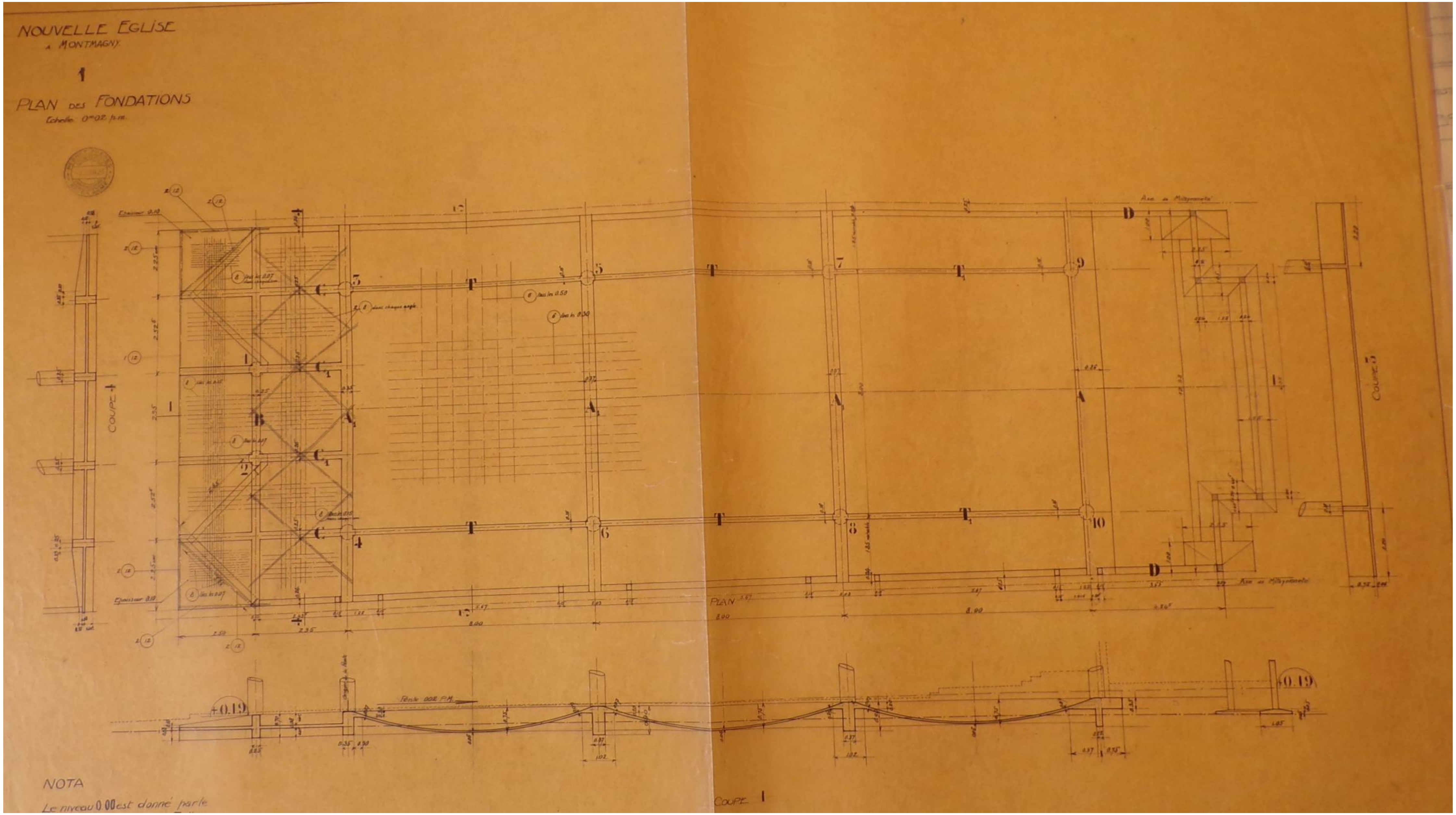


Auguste Perret,
Docks Wallut, 1916



Auguste Perret, Société Paris-Maroc 1920

Auguste Perret,
Ste Thérèse,
Montmagny,
1925



Auguste Perret, Ste Thérèse, Montmagny, 1925; vaulted foundation

In recent years, a few historians of science have been finding it more and more difficult to fulfil the functions that the concept of development-by-accumulation assigns to them. As chroniclers of an incremental process, they discover that additional research makes it harder, not easier, to answer questions like: When was oxygen discovered? Who first conceived of energy conservation? Increasingly, a few of them suspect that these are simply the wrong sorts of questions to ask.

T.S. Kuhn *The structure of scientific revolutions*

What is a concrete thin-shell structure?

and does the definition exclude Perret's shells?

Stiffened

‘The Paraboloid’
Denver, CO 1966
I.M. Pei
Anton Tedesko

Beam-Supported

Photo: Alan Karchner
Historic New Orleans
Collection

Rivergate Convention
Center, New Orleans, LA
1966

Photo: Dalton Woolverton

Zeiss-Dywidag System: Loring AFB, Anton Tedesko 1947-9

Photo: Seattle Times

The Kingdone,
Seattle, WA 1973

Jack Christiansen

Louis Gellusseau

Le Génie Civil, 1922

VI. Arc parabolique surbaissé (fig. 20). — Pour une flèche f inférieure à $\frac{L}{5}$ (arcs de *ponts surbaissés*, ou *voûtes de planchers*), les déformations dues à N et à T ne sont plus négligeables par rapport à celles dues à M, comme on le verra par les valeurs des termes qui en résultent.

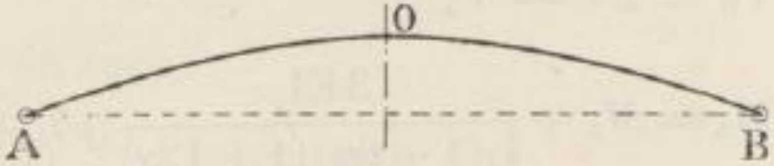


Fig. 20.

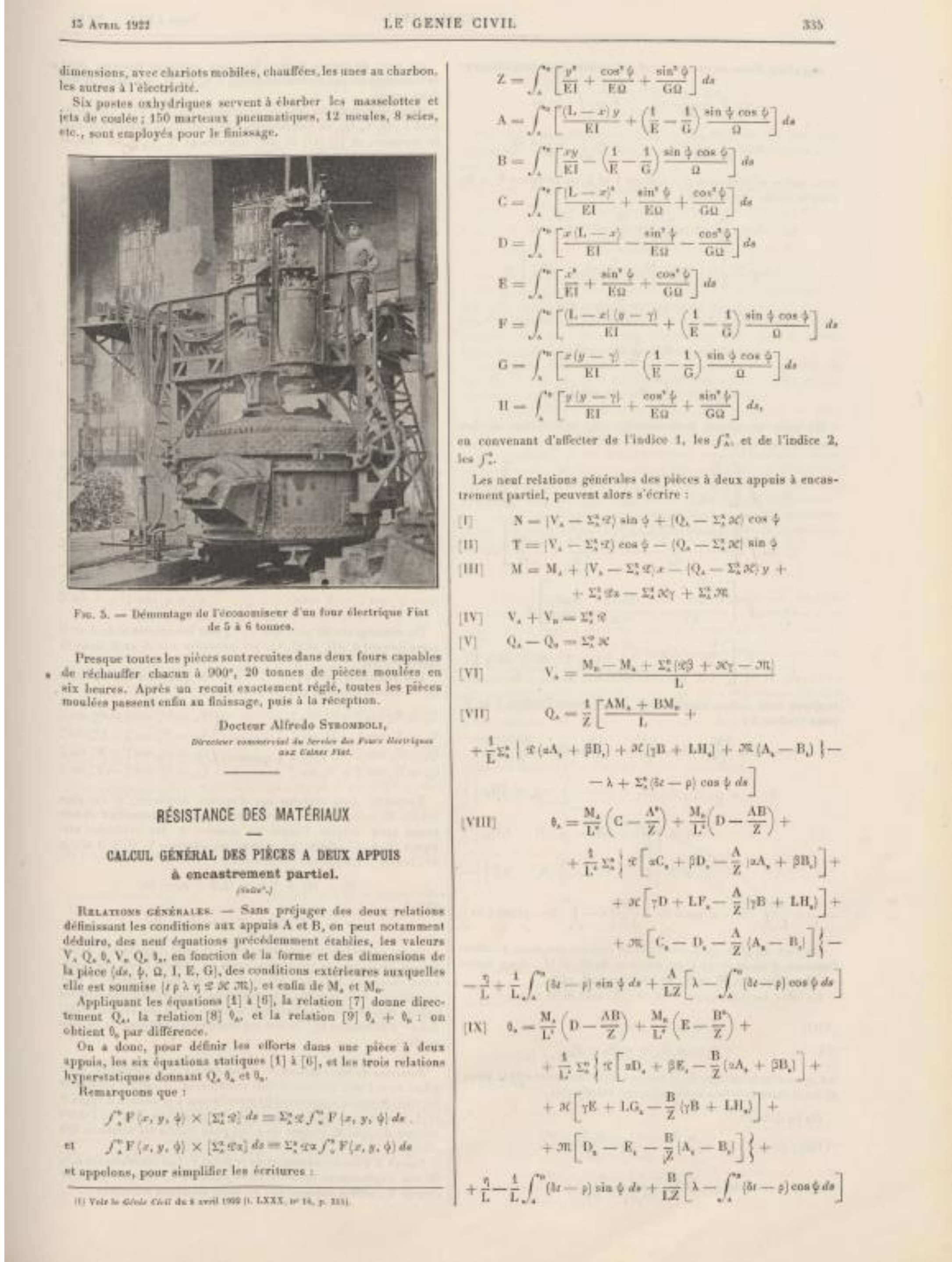
Mais alors l'angle ψ reste très petit, cos ψ très voisin de l'unité, en sorte que l'on peut toujours considérer que l'on a, en chaque point :

$$I = \frac{I_0}{\cos \psi} \qquad \Omega = \frac{\Omega_0}{\cos \psi},$$

d'où

$$\frac{ds}{I} = \frac{dx}{I_0} \qquad \frac{ds}{\Omega} = \frac{dx}{\Omega_0} = i^2 \frac{dx}{I_0},$$

Louis Gellusseau



dimensions, avec chariots mobiles, chauffées, les unes au charbon, les autres à l'électricité.

Six postes oxhydriques servent à ébarber les masselottes et jets de coulée ; 150 marteaux pneumatiques, 12 meules, 8 scies, etc., sont employés pour le finissage.

Fig. 5. — Démontage de l'économiseur d'un four électrique Fiat de 5 à 6 tonnes.

Presque toutes les pièces sont recuites dans deux fours capables de réchauffer chacun à 900°, 20 tonnes de pièces moulées en six heures. Après un recuit exactement réglé, toutes les pièces moulées passent enfin au finissage, puis à la réception.

Docteur Alfredo Strombolі,
Directeur commercial du Service des Fours électriques aux Usines Fiat.

RÉSISTANCE DES MATÉRIAUX

CALCUL GÉNÉRAL DES PIÈCES A DEUX APPUIS à encastrement partiel.

(Suite[1].)

Relations générales. — Sans préjuger des deux relations définissant les conditions aux appuis A et B, on peut notamment déduire, des neuf équations précédemment établies, les valeurs $V_A\ Q_A\ \theta_A\ V_B\ Q_B\ \theta_B$, en fonction de la forme et des dimensions de la pièce (ds, ψ, Ω, I, E, G), des conditions extérieures auxquelles elle est soumise ($t\ \rho\ \lambda\ \eta\ \mathcal{V}\ \mathcal{H}\ \mathcal{M}$), et enfin de M_A et M_B.

Appliquant les équations [1] à [6], la relation [7] donne directement Q_A, la relation [8] θ_A, et la relation [9] $\theta_A + \theta_B$: on obtient θ_B par différence.

On a donc, pour définir les efforts dans une pièce à deux appuis, les six équations statiques [1] à [6], et les trois relations hyperstatiques donnant $Q_A\ \theta_A$ et θ_B.

Remarquons que :

$$\int_A^B F(x, y, \psi) \times [\Sigma_A^s \mathcal{V}]\, ds = \Sigma_A^B \mathcal{V} \int_s^B F(x, y, \psi)\, ds$$

et

$$\int_A^B F(x, y, \psi) \times [\Sigma_A^s \mathcal{V}\alpha]\, ds = \Sigma_A^B \mathcal{V}\alpha \int_s^B F(x, y, \psi)\, ds$$

et appelons, pour simplifier les écritures :

$$Z = \int_A^B \left[\frac{y^2}{EI} + \frac{\cos^2\psi}{E\Omega} + \frac{\sin^2\psi}{G\Omega}\right] ds$$

$$A = \int_A^B \left[\frac{(L-x)\,y}{EI} + \left(\frac{1}{E} - \frac{1}{G}\right)\frac{\sin\psi\cos\psi}{\Omega}\right] ds$$

$$B = \int_A^B \left[\frac{xy}{EI} - \left(\frac{1}{E} - \frac{1}{G}\right)\frac{\sin\psi\cos\psi}{\Omega}\right] ds$$

$$C = \int_A^B \left[\frac{(L-x)^2}{EI} + \frac{\sin^2\psi}{E\Omega} + \frac{\cos^2\psi}{G\Omega}\right] ds$$

$$D = \int_A^B \left[\frac{x(L-x)}{EI} - \frac{\sin^2\psi}{E\Omega} - \frac{\cos^2\psi}{G\Omega}\right] ds$$

$$E = \int_A^B \left[\frac{x^2}{EI} + \frac{\sin^2\psi}{E\Omega} + \frac{\cos^2\psi}{G\Omega}\right] ds$$

$$F = \int_A^B \left[\frac{(L-x)(y-\gamma)}{EI} + \left(\frac{1}{E} - \frac{1}{G}\right)\frac{\sin\psi\cos\psi}{\Omega}\right] ds$$

$$G = \int_A^B \left[\frac{x(y-\gamma)}{EI} - \left(\frac{1}{E} - \frac{1}{G}\right)\frac{\sin\psi\cos\psi}{\Omega}\right] ds$$

$$H = \int_A^B \left[\frac{y(y-\gamma)}{EI} + \frac{\cos^2\psi}{E\Omega} + \frac{\sin^2\psi}{G\Omega}\right] ds,$$

en convenant d'affecter de l'indice 1, les $\int_A^s$, et de l'indice 2, les $\int_s^B$.

Les neuf relations générales des pièces à deux appuis à encastrement partiel, peuvent alors s'écrire :

[I] $$N = (V_A - \Sigma_A^s \mathcal{V}) \sin\psi + (Q_A - \Sigma_A^s \mathcal{H}) \cos\psi$$

[II] $$T = (V_A - \Sigma_A^s \mathcal{V}) \cos\psi - (Q_A - \Sigma_A^s \mathcal{H}) \sin\psi$$

[III] $$M = M_A + (V_A - \Sigma_A^s \mathcal{V})\, x - (Q_A - \Sigma_A^s \mathcal{H})\, y + \Sigma_A^s \mathcal{V}\alpha - \Sigma_A^s \mathcal{H}\gamma + \Sigma_A^s \mathcal{M}$$

[IV] $$V_A + V_B = \Sigma_A^B \mathcal{V}$$

[V] $$Q_A - Q_B = \Sigma_A^B \mathcal{H}$$

[VI] $$V_A = \frac{M_B - M_A + \Sigma_A^B (\mathcal{V}\beta + \mathcal{H}\gamma - \mathcal{M})}{L}$$

[VII] $$Q_A = \frac{1}{Z}\left[\frac{AM_A + BM_B}{L} + \frac{1}{L}\Sigma_A^B \left\{ \mathcal{V}(\alpha A_1 + \beta B_1) + \mathcal{H}(\gamma B + LH_1) + \mathcal{M}(A_1 - B_1) \right\} - \lambda + \Sigma_A^B (\delta t - \rho) \cos\psi\, ds\right]$$

[VIII] $$\theta_A = \frac{M_A}{L^2}\left(C - \frac{A^2}{Z}\right) + \frac{M_B}{L^2}\left(D - \frac{AB}{Z}\right) + \frac{1}{L^2}\Sigma_A^B \left\{ \mathcal{V}\left[\alpha C_2 + \beta D_2 - \frac{A}{Z}(\alpha A_2 + \beta B_2)\right] + \mathcal{H}\left[\gamma D + LF_2 - \frac{A}{Z}(\gamma B + LH_2)\right] + \mathcal{M}\left[C_2 - D_2 - \frac{A}{Z}(A_2 - B_2)\right] \right\} - \frac{\eta}{L} + \frac{1}{L}\int_A^B (\delta t - \rho) \sin\psi\, ds + \frac{A}{LZ}\left[\lambda - \int_A^B (\delta t - \rho) \cos\psi\, ds\right]$$

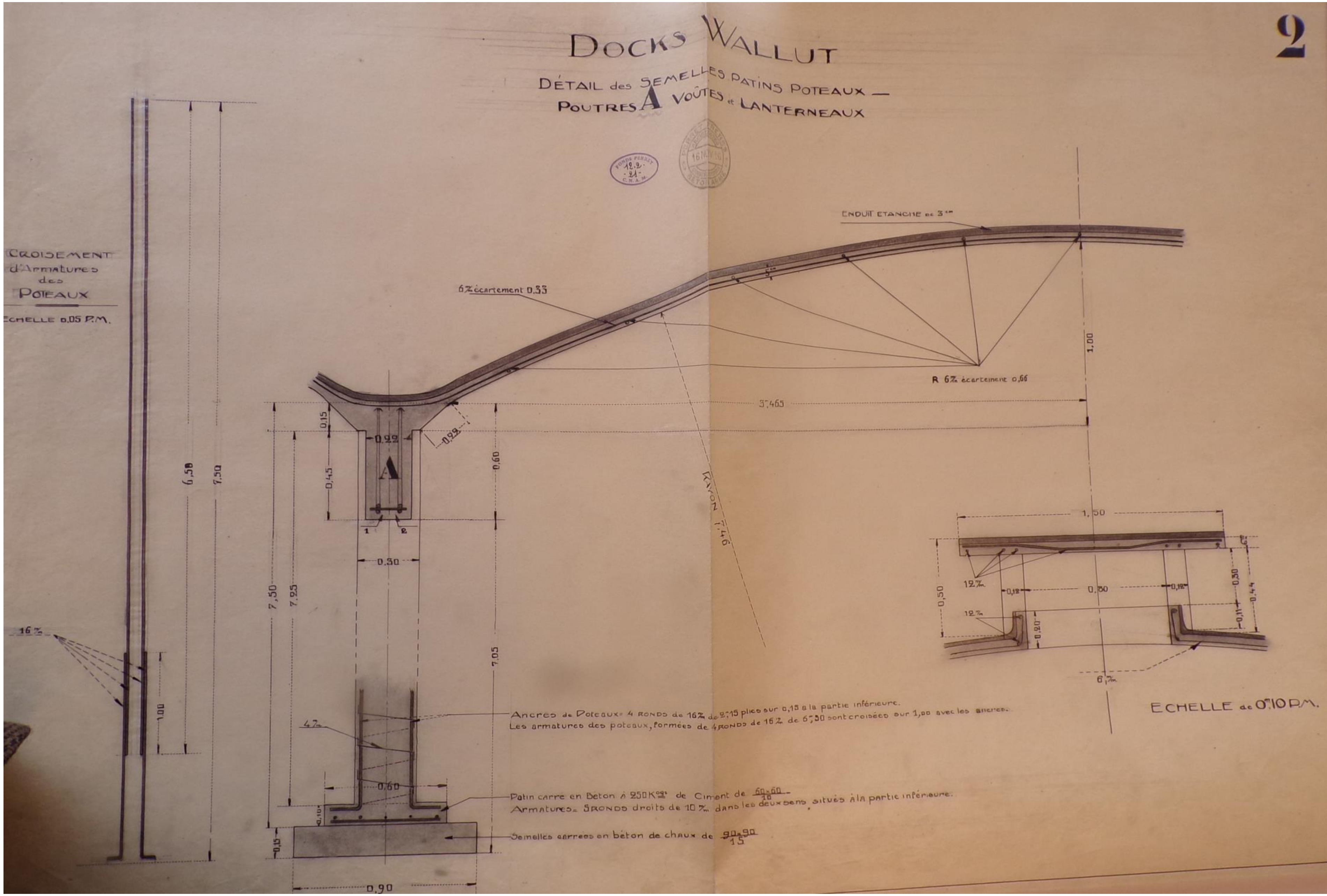
[IX] $$\theta_B = \frac{M_A}{L^2}\left(D - \frac{AB}{Z}\right) + \frac{M_B}{L^2}\left(E - \frac{B^2}{Z}\right) + \frac{1}{L^2}\Sigma_A^B \left\{ \mathcal{V}\left[\alpha D_2 + \beta E_2 - \frac{B}{Z}(\alpha A_2 + \beta B_2)\right] + \mathcal{H}\left[\gamma E + LG_2 - \frac{B}{Z}(\gamma B + LH_2)\right] + \mathcal{M}\left[D_2 - E_2 - \frac{B}{Z}(A_2 - B_2)\right] \right\} + \frac{\eta}{L} - \frac{1}{L}\int_A^B (\delta t - \rho) \sin\psi\, ds + \frac{B}{LZ}\left[\lambda - \int_A^B (\delta t - \rho) \cos\psi\, ds\right]$$

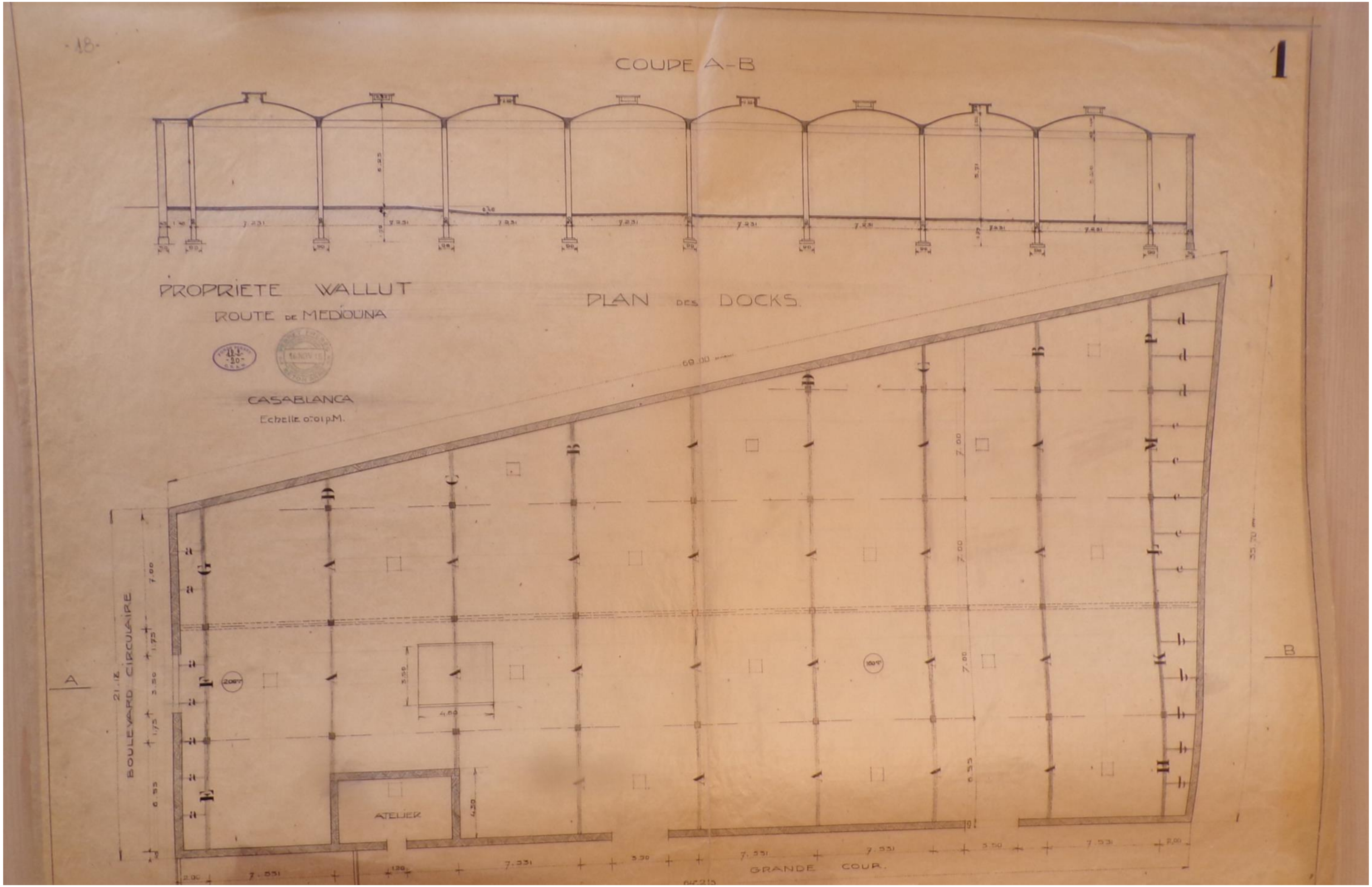
(1) Voir le *Génie Civil* du 8 avril 1922 (t. LXXX, n° 14, p. 315).

Le Génie Civil, 1922

Docks Wallut, 1917: A beam-supported segmental thin-shell

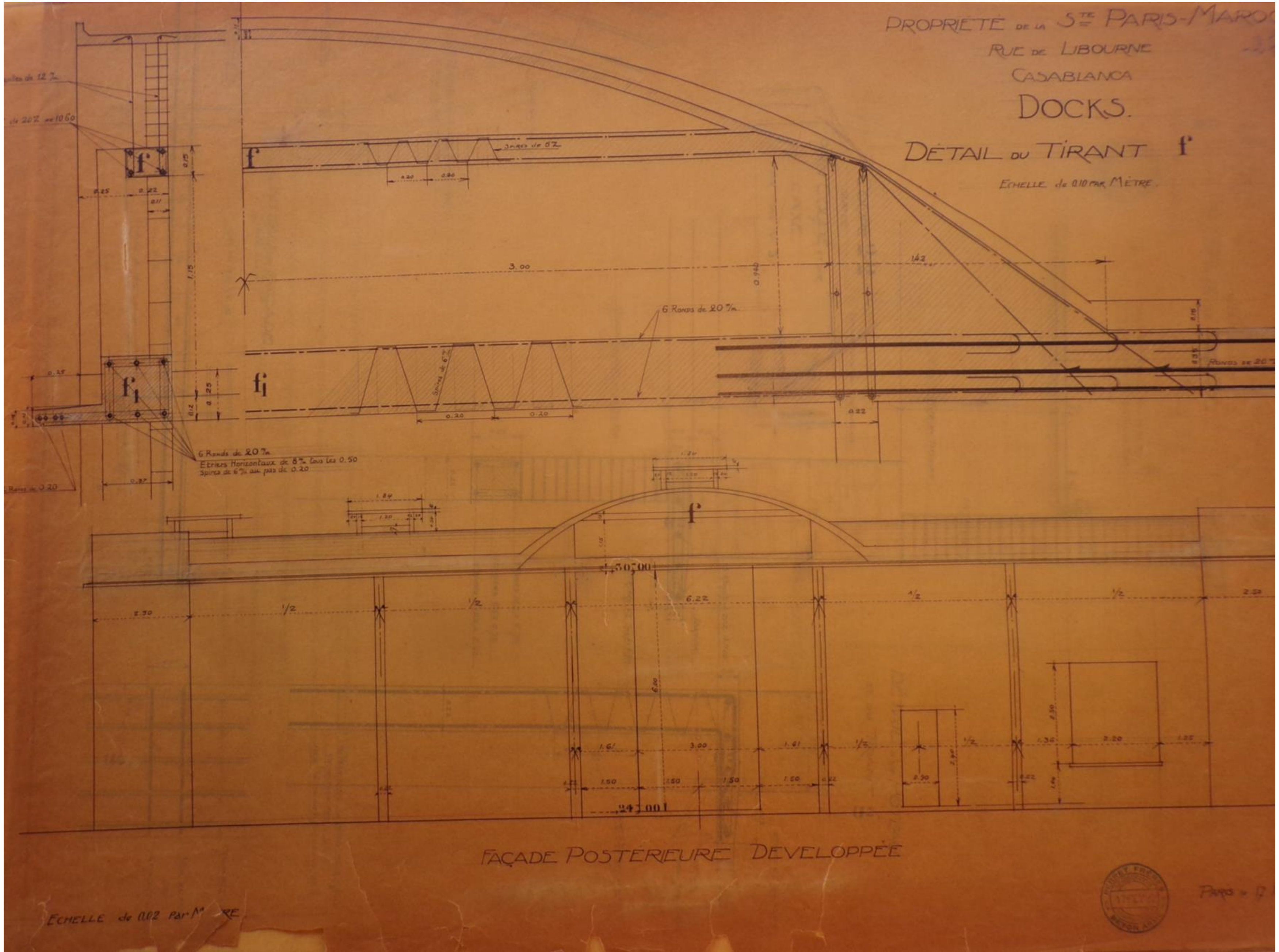
Auguste Perret



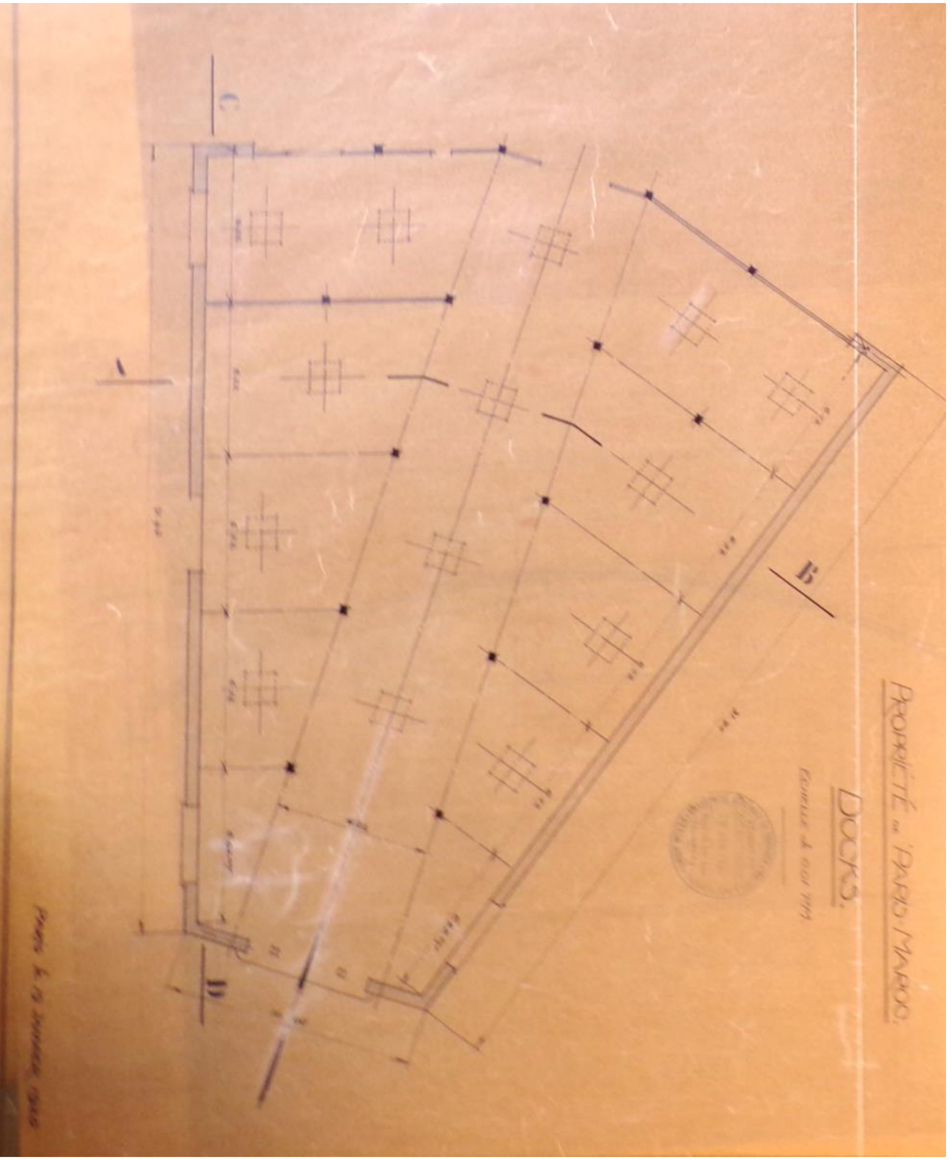


18
1
COUPE A-B
PROPRIETE WALLUT
ROUTE DE MEDIOUNA
PLAN DES DOCKS
CASABLANCA
Echelle 0.01 p.M.
BOULEVARD CIRCULAIRE
ATELIER
GRANDE COUR
A
B

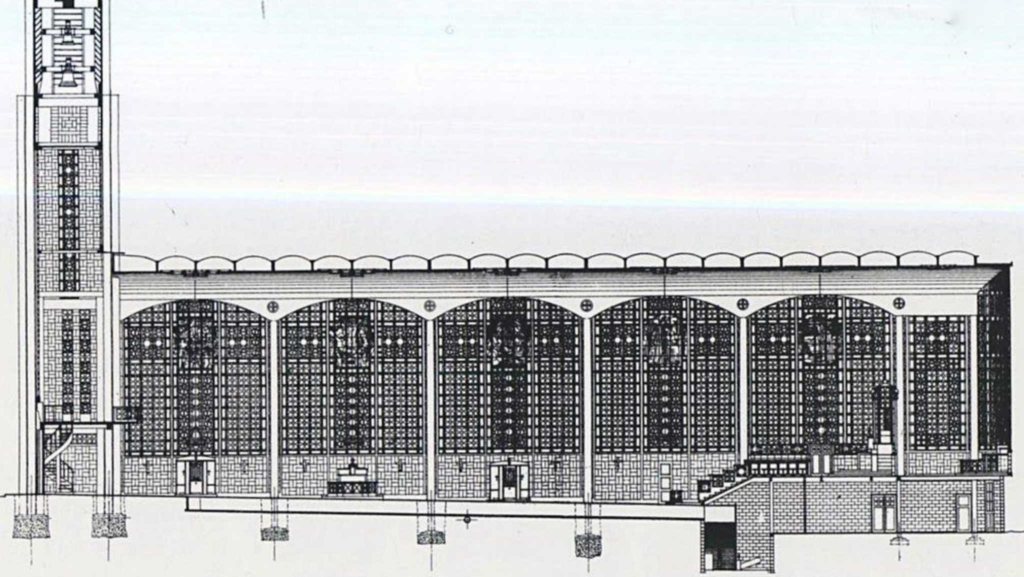
Société Paris-Maroc, 1920. A beam-supported segmental thin-shell

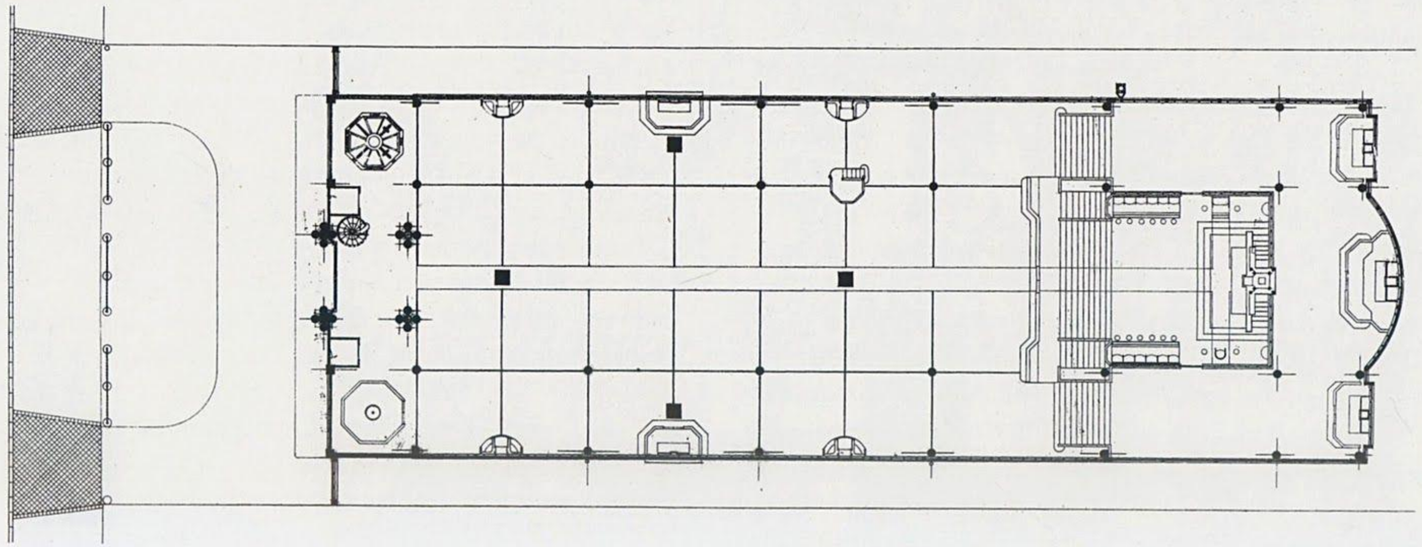


Société Paris-Maroc, 1920. Possibly a structural model for Notre-Dame de la Consolation, Le Raincy France

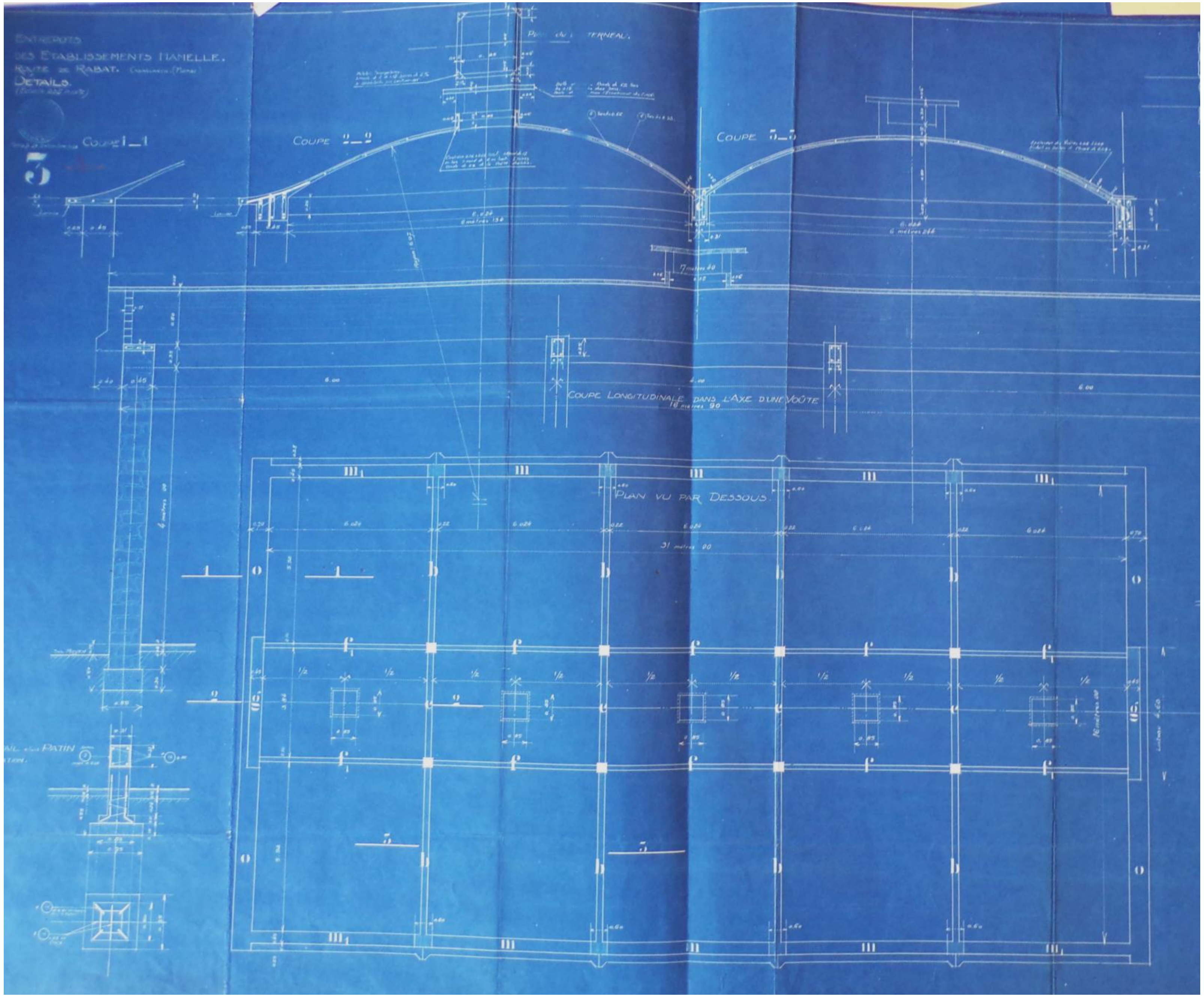


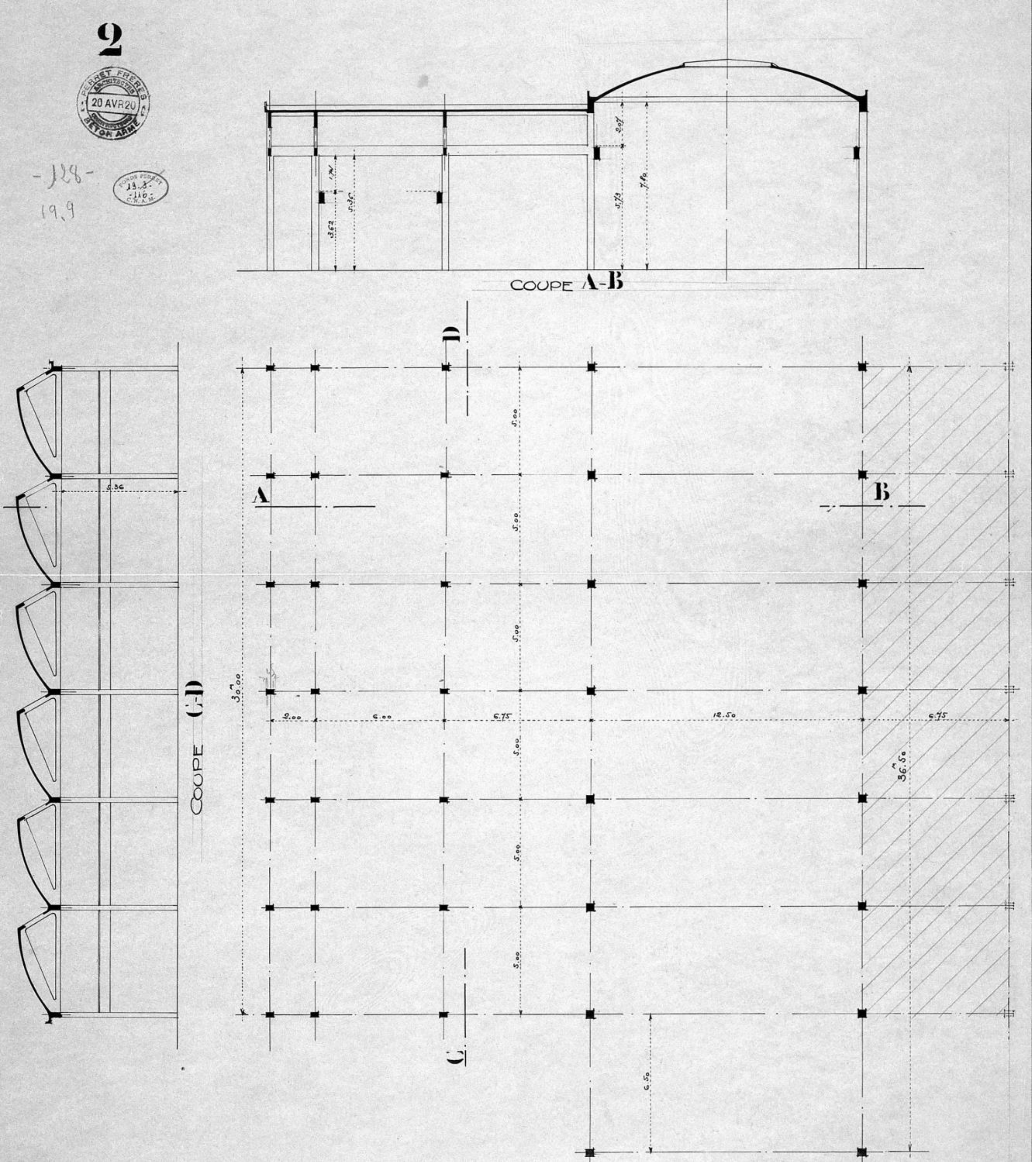
(à droite) Notre-Dame du Raincy, coupe longitudinale.
(ci-dessous) Notre-Dame du Raincy, plan.





Entrepôts Hamel, Auguste Perret, 1923: A beam-supported segmental shell





Voirin-Marinoni Factory, Montataire, France
Auguste Perret, 1920

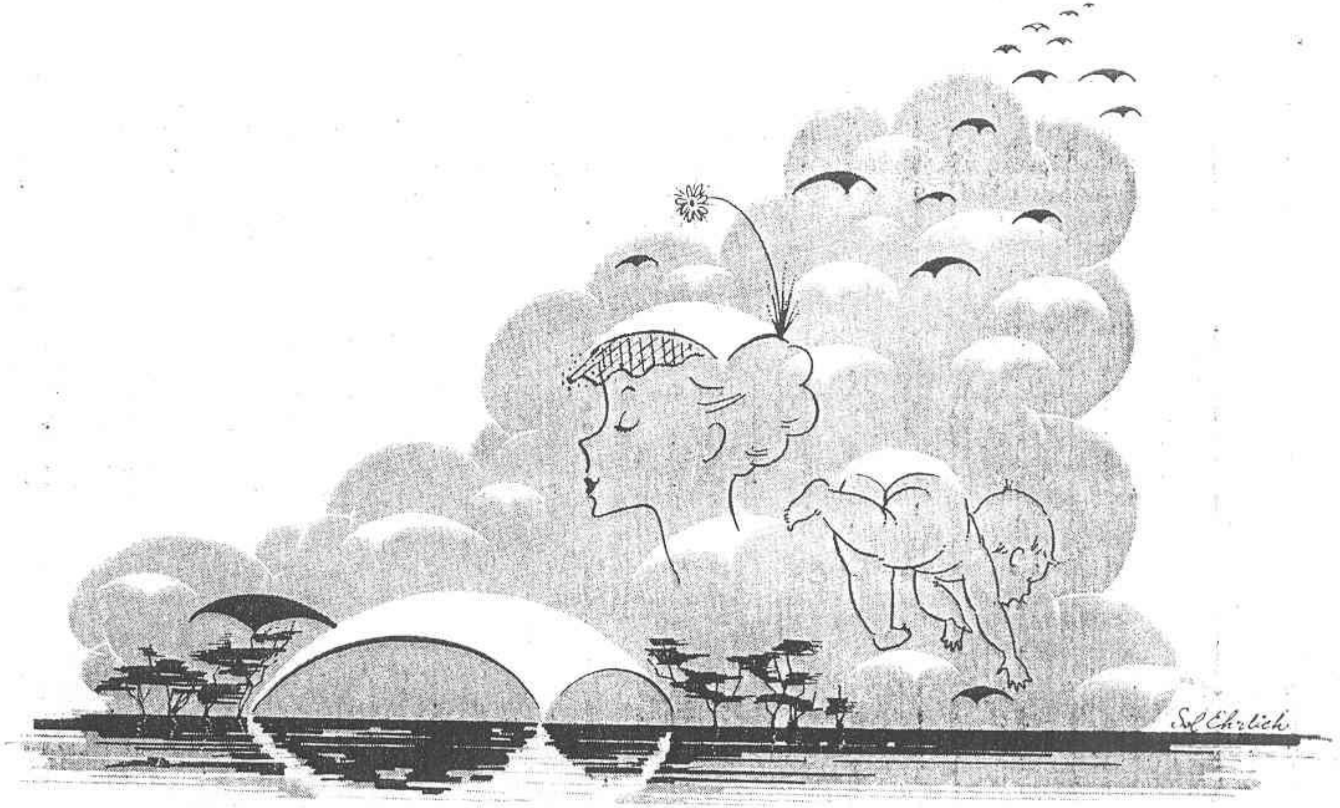
It is also noteworthy that the evolution from sheds to shell is a consequence of the Perret brothers' choice to use for Marinoni the curved formworks developed for the Wallut and Grange foundries.

Guy Lambert and Franz Graf

The sheds of the Voirin-Marinoni factory at Montataire

‘Designed by Eero Saarinen of TWA Flight Center fame, Kresge serves as a well known example of thin shell concrete structure’

https://studentlife.mit.edu/cac/event-services-spaces/event-spaces/kresge-auditorium



THE OPAL ON THE CHARLES

***By Edward Weeks**, Editor, The Atlantic Monthly*

Photo:
MIT Museum

Photo:
MIT Museum

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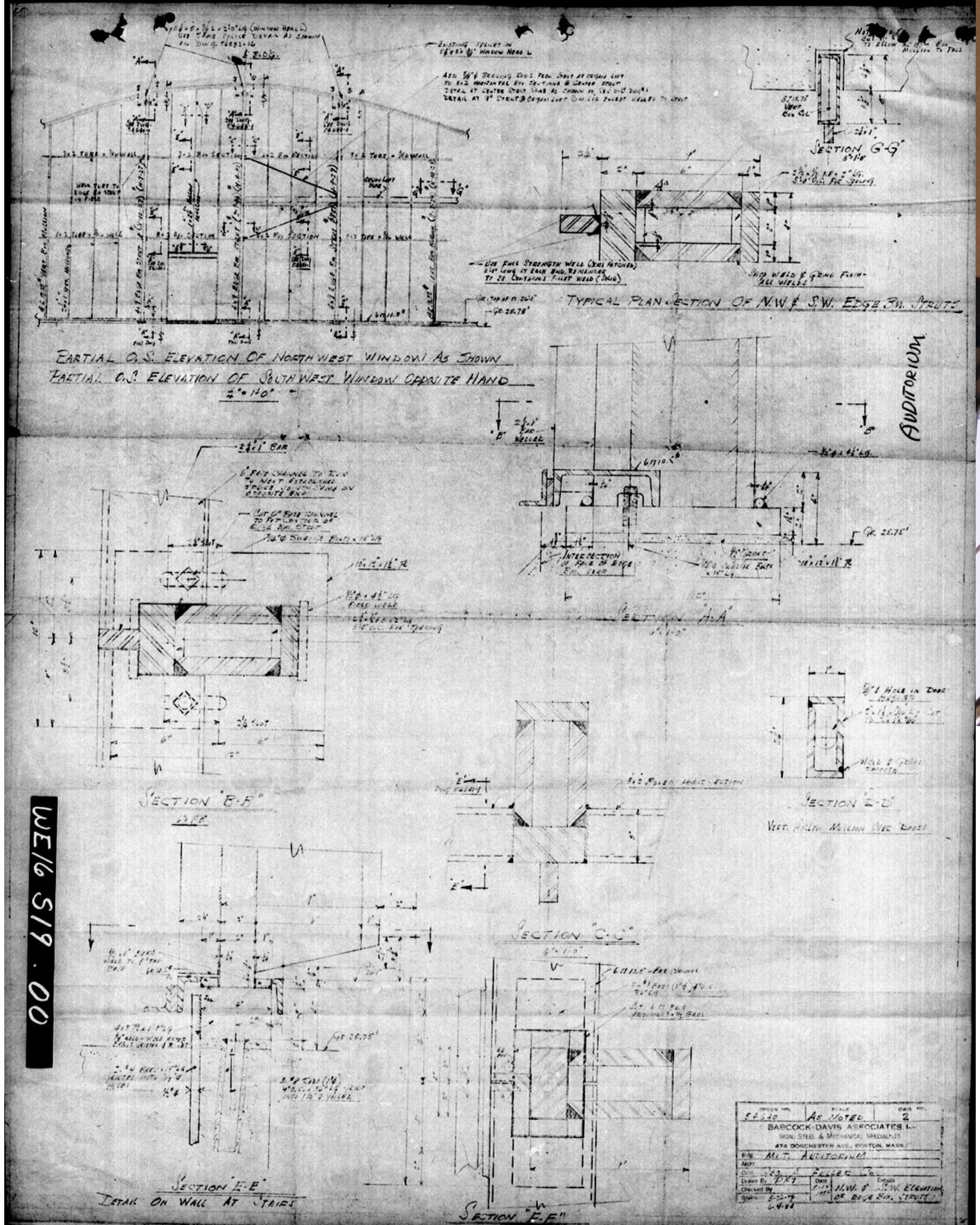

Archival material:
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Conclusions

It is difficult to pinpoint the exact date and the exact inventor of a new system. It is more illuminating to describe the context in which an invention appeared and the experimentation that led to the final, refined product.

The definition of a ‘thin-shell concrete’ structure is elusive and influences the discussion of the inventor of this construction type.

Empirically designed thin shells were constructed years before methods were available to calculate the stresses in thin shells.

Beginning in 1917, Auguste Perret, an innovator in concrete construction and concrete architecture, and his collaborator Louis Gellusseau built segmental thin-shell concrete structures with spans over 7 meters and thickness from 3-5 centimeters

Acknowledgments

Perret Archive: Centre d’archives d’architecture contemporaine

Guy Lambert; INSA Paris