SHELL SELLERS. THE INTERNATIONAL DISSEMINATION OF THE ZEISS-DYWIDAG SYSTEM, 1923–1939

Roland May

Keywords
Thin concrete shells, Dyckerhoff & Widmann (Dywidag), Zeiss-Dywidag (Z-D) system, Chisarc system, knowledge transfer

Abstract
No history of modern building construction can avoid making reference to the Zeiss-Dywidag (Z-D) system. It will tell in brief the story of a nondescript test planetarium that had been erected 1922/23 on a factory roof in the Zeiss works at Jena, Germany, and that became the cradle of modern thin concrete shell construction. It will furthermore narrate how the building company Dyckerhoff & Widmann (Dywidag) developed out of this prototype within a couple of years an array of different shell constructions that gained world-wide fame such as the Frankfurt and Leipzig Market Halls. And, it will usually mention their planers, in particular Franz Dischinger and Ulrich Finsterwalder – names who are well-known to engineers dealing with thin shell constructions until today.

Despite this extensive reputation, the Zeiss-Dywidag system usually is depicted as a significant contribution of the “German School” of engineering that – notwithstanding its fame – mainly was of local importance for thin concrete shell design. Consequently, no thorough study on the Zeiss-Dywidag system’s influence on the early international development of thin concrete shell construction has been carried out so far. An important process of knowledge transfer during the beginnings of thin concrete shell construction therefore has widely fallen into oblivion.

This paper wants to recall the fact that there were successful efforts to promote and establish the Z-D system far beyond the German borders. It describes the global dissemination of the Z-D system before the outbreak of the Second World War, which gave a vast number of engineers on four continents a first possibility of gaining practical experience in the erection of thin concrete shells. Furthermore, it reveals that the underlying concepts were acting as important stimulators for a world-wide growth in the examination of shell theories.
INTRODUCTION

“Very little [...] about the international use of this construction type has become known to the public, even though it has been widely applied in most countries around the world.”

Hubert Rüschi (1939)

The beginnings of building with thin concrete shells can be traced back to the nineteenth century. However, the international historiography studying this building type usually begins with a nondescript experimental planetarium erected 1922/23 on the roof of a factory building belonging to the optical company Carl Zeiss at Jena. This prototype developed by Zeiss engineer Walther Bauersfeld in cooperation with the building company Dyckerhoff & Widmann (Dywidag) boasted of a shotcreted network dome. The structure was essential for the future development of shell construction: For the first time current theoretical knowledge pertaining to the membrane theory from the field of applied mechanics had been implemented into practical building with reinforced concrete.

THE ZEISS-DYWIDAG SYSTEM: A GERMAN SONDERWEG?

Based on the experience derived from this pioneering structure, it took only a few years of a fascinating interplay between theory creation and immediate practical implementation to generate the fundamental knowledge for shell construction. Crucial in this process was the development of the long barrel shell, initially driven by Dywidag’s senior engineer Franz Dischinger, but subsequently ceded to his assistant Ulrich Finsterwalder (cfr. May 2012). Its usability for roofing large areas was soon impressively demonstrated with the Frankfurt Market Hall (1926–28). Wide attention attracted also Leipzig’s Market Hall (1927–29), as its two octagonal shell domes set a new world record span for massive domes. An experimental translation shell with synclastic double curvature on a square plan construction, built in 1931 on the Dywidag premises, was another instance to impress engineers world-wide. The photo of Dywidag’s staff on top of the 1.5cm-thin roof became a stock image in the historiography of structural engineering.

Yet, this is also where the scientific narrative of the shell system Zeiss-Dywidag (Z-D) usually ends. Literature on shell construction regularly proceeds from here to works of Eduardo Torroja and Robert Maillart or – to a lesser extent – to achievements by Fernand Aimon and Bernard Lafaille in the 1930s. Skipping the 1940s, the story goes on with Félix Candela’s early designs from around 1950, usually seen as the prelude to the genuine epoch of shell construction.

There are very few exceptions to this virtually canonic account, which implies the Z-D system became extinct without producing real offspring. Among these David P. Billington’s ample work is most notable, although he mainly emphasized the contrast of the Z-D system as a product fed by theory with the former Dywidag engineer Anton Tedesko’s approach towards shell design, which he acclaimed for relying much more on intuition and experimentation, instead. In fact, one has to concede that the path of the Dywidag engineers – paved to a large extent by mathematics – remained somewhat unfamiliar among structural engineers. Consequently, many of them considered the highly complex calculation of Z-D shells “a sort of transcendental mystery only divested by the German school” (Pizzetti 1958).

FIRST INSTANCES OF INTERNATIONAL RECEPTION

Despite this certain reluctance already the first Z-D rotational shells impressed the international engineering community. They were seen as ultra-modern and thus ideal envelopes for the
first projection planetariums, the so-called “Miracle of Jena”. Just some months after completion of the prototype Catalan architect Josep Puig i Cadafalch approached Zeiss, because he wanted to apply exactly such a modern structure for the Barcelona World Exhibition’s Gran Palau de les Nacions (Panyella 1924). But his project, having almost reached the execution stage, fell prey to Primo de Rivera’s coup d’état.

The range for applications of domes, however, was quite limited. So this new construction type did not see many attempts of realization. Yet, Dischinger’s first report on Z-D domes from 1925 was immediately commented in expert journals from countries such as Belgium, The Netherlands, Italy or Sweden. Its main contents were also presented in Engineering Progress and El Progreso de la Ingeniería, magazines promoting German engineering achievements abroad.

Even more impression left Dischinger’s contribution to the Handbuch für Eisenbetonbau (Dischinger 1928), presenting “for the first time both a systematic analysis procedure and a variety of completed examples of concrete shells” (Billington 1982). An important part of the treatise was dedicated to Z-D barrel shells, being described here for the first time at great depth.

COMMENCING A STRATEGY OF INTERNATIONALIZATION

Dischinger also discussed an airplane hangar built in Kaunas for the Lithuanian air force in 1927/28, being the first application of Z-D barrel shells abroad. The swift process of internationalization was in part owed to the situation on the home market where Dywidag did not make profits due to the fierce competition with steel construction. Thus by the spring of 1927 Dywidag had addressed the international market through an extensive promotion booklet, presenting the portfolio in German, English, French and Spanish (N.N. 1927).

The essential requirement for international expansion had already been established before. Being the sole holder of the right to apply for shell construction patents thanks to an internal agreement, Zeiss had begun as early as 1923 with the continuous safeguarding of patent rights in foreign countries. Still, it was extremely difficult for building companies in those days to conquer foreign markets. Hence, even though Dyckerhoff & Widmann had executed quite a few projects abroad and was able to build the first commissions outside of Germany by subsidiaries, the company also looked for foreign licensees.

Their very first licensee, contracted in 1928, directly seemed like a big coup: It was Henry Lossier, one of the most prominent civil engineers at the time. But Lossier’s attempts to establish the Z-D-system in France miscarried. The local tradition of shell construction, amply displayed...
in Eugène Freyssinet’s works, was too deeply entrenched. More promising was the commitment of Rodolfo Stoelcker, a building contractor of German descent, as a licensee for Italy. By the end of 1928 he had already secured his first commission.

In general, the first efforts to gain a foothold on the international market yielded meager results: the Kaunas hangar, a nitrogen depot in Wyry, Poland, plus network projection domes for the planetariums in Rome and Moscow by order of Zeiss. However, the sum of 5,000 m² of shell surface from these four structures accounted for nearly 30% of 1928’s total production.

**Figure 3: Budapest Market Hall, rendering of the interior from the 1931 Z-D promotion booklet (N.N. 1931)**

### Boosting of International Sales during the Great Depression

The further growth of foreign business would greatly benefit from an increasing number of international publications on Z-D shell construction, some of which had been written by Dywidag staff themselves. A piece with particular resonance was Dischinger’s contribution to the 1930 *International Congress for Concrete and Reinforced Concrete* in Liège (Dischinger 1931), where almost all “of the eminent men whose names are by-words in this branch of engineering were present” (Stern 1931). Dischinger made his presentation a parade of designs and applications in shell construction’s past and possible future. Finsterwalder, on the other hand, presented just the Budapest Market Hall (1930/31) in the newly founded *IABSE publications* two years later (Finsterwalder 1932). The article proved to be as influential, nevertheless, as he thoroughly discussed his simplified bending theory for segmented circular cylindrical shells.

Sales abroad had already left the domestic mark et far behind, when a revised edition of the Z-D promotion booklet displayed the latest achievements in 1931 (N.N. 1931). Between 1929 and 1933 almost two thirds of all Z-D shells, comprising nearly 100,000 m² of shell surface, were erected in foreign countries. During those difficult years of the Great Depression the international business had become a decisive support.

Dywidag subsidiaries in Uruguay and Argentina erected seven edifices with shell roofs in this period. Nearly all other commissions – some three quarters of all constructions abroad – were performed by licensees, whose number had meanwhile risen to nine. Zeiss, as patent holder, usually received a license fee of 0.33 Reichsmark per square meter shell surface. Dywidag secured their share by acting as consulting engineers for those highly complex constructions, producing calculations as well as construction drawings at their headquarters. In addition they sent experienced site managers to assist each licensee on-site during their first execution of a thin concrete shell.
Most orders were for constructions with barrel shells, exceptions being rotational domes produced in cooperation with Lossier for Algiers and Mulhouse/Alsace as well as polygonal shell domes for Basle, Rome and Gdynia/Poland. Custom-made and innovative solutions were often needed to meet with the requirements of the local building traditions as well as the different economic situations prevailing in the respective countries. One of the most striking results of these circumstances was the abandoning of the design-shaping Zeiss network. Actually a core element of a Zeiss-Dywidag shell, it was left out in most of the buildings abroad.

CONQUERING NEW MARKETS

The momentous year 1933 also marked a turning point for the Z-D system: In the summer of that year Dischinger left Dywidag. Only a couple of weeks later Z-D shell construction would begin to profit immensely from the NS rearmament policy under his successor Finsterwalder. At first there was a huge demand for aircraft hangars from the Luftwaffe, followed later by large-scale armament production plants with saw-tooth shell roofs. All meant that Germany retook its position as stronghold of Z-D shell production while commissions abroad accounted only for a mere quarter of the total output between 1934 and 1939. Nonetheless, that still meant a substantial manufacture of 180,000 m² of shell surface. In comparison to the previous six-year period foreign production had thus increased by 80%, with the number of commissions even doubled. Furthermore, nearly another ten countries had been included into the Z-D family.

By now Z-D shells had become a profitable business. In the year 1935 the Zeiss company received license fees of nearly 5,000 US$ but only paid some 700 US$ for its 35 patents in 18 countries or colonies respectively. Works abroad were also prospering for Dywidag. In addition to the well-running commercial operations in Southeast Europe, Italy and South America two new important business ties could be established: Accumulating more than ten commissions each until the end of the decade, both Great Britain and the US became crucial outlets for Z-D shells.

Based on an agreement with Roberts & Schaefer Co. Dywidag engineer Anton Tedesko acted as a permanent representative of his company in the licensee’s Chicago headquarters since early 1932. In Great Britain the joint venture Humphreys-Dywidag Ltd. was originally thought to sell the shell constructions, but this cooperation proved unfruitful. A license agreement was therefore signed in 1934 with the architect T.A. Chisholm, who was supported by the former Dywidag engineer Charles Frédéric de Steiger. Chisholm’s London-based firm Architectural Services Ltd. would henceforth promote Z-D shells under the name Chisarc system. First small scale commissions could be acquired in 1934 in the US and a year later in Great Britain. Despite being hin-
INFLUENCES ON THE INTERNATIONAL DEVELOPMENT

The US and Great Britain are also good examples for a slowly increasing design autonomy of the licensees in the course of the 1930s, even though Hubert Rüsch – one of the central figures of Z-D shell design – emphasized as late as 1939 “that even in the case of buildings in overseas countries all structural details are elaborated in Germany” (Rüsch 1939). By that time, both Anton Tedesko with his Roberts & Schaefer colleagues and Henry George Cousins, consulting engineer to Architectural Services, already developed their respective projects widely independent. In fact, Rüsch himself had already been designing shells in Argentina virtually autonomous between 1931 and 1934.

But also in other countries a steadily growing number of engineers – some of them connected to Dywidag, others autonomously – came up with their own interpretations of Z-D shell construction. In the first instance this tendency became manifest in countries without patent protection, with prominent examples being the foundry halls for the Soviet Dneprovsk Aluminum Combine at Zaporozh'ye (1931–33) or Larsen & Nielsen’s hangars at Værløse aerodrome (1934–38) in Denmark. A peculiar case are the shell roofs from A.S. Joffe & Co. in South Africa, as the company had signed a Z-D license contract in 1933, but never paid any fees.

Simultaneously a growing number of engineers showed themselves at least inspired by Z-D shell constructions with a lot of them also relying on the Dywidag engineers’ calculation methods. Their most prominent representative is Eduardo Torroja, others have sunken slightly into oblivion such as the Italian Dante Fornasir, Waclaw Żenczykowski from Poland, the Norwegian Dischinger disciple Andreas Aas-Jakobsen or Atilio D. Gallo from Buenos Aires.

Stimulated by translations of essential contributions (Dischinger 1932, Issenmann Pilarski 1935) as well as by the latest writings from the former Dywidag engineers Wilhelm Flügge (1934) and Dischinger (1935), the numerous practical executions were accompanied since the mid 1930s by a virtually explosive growth of literature on theoretical issues. Bibliographies on the subject produce ample evidence that the pleasure of playing with very sophisticated differential equations persisted by no means as a monopole of the “German School”. Initially shrouded in mystery, Z-D shells had developed into the most important stimulator for shell theory examinations – even in countries like Sweden, where no such structures had been built.
CONCLUSIONS

If we consider not only executed projects but also Z-D shells built without a valid license, registered patents and unrealized proposals from Dywidag, then at least 35 countries and colonies, respectively, came into direct contact with the Z-D system between 1923 and 1939. Some 100 licensed constructions were outside of Germany in this period. Their total shell surface of more than 280,000 m² was roughly a third of the overall Z-D shell production until 1939.

Building with shells in foreign countries, however, was not merely a question of quantity; the individual constructions also produced a lot of quality in the Z-D universe. A great number of structural innovations was realized for the first time in countries other than Germany: consequent modeling of the segmented circular cylindrical shell (airplane hangar, Kaunas, 1927/28), flat rotational shell on single supports (Salle des Arts du Gouvernement Général, Algiers, 1929/30), four-sided polygonal shell (Fiat showroom, Rome, 1931), saw-tooth shell roof (textile factory Grafà, Buenos Aires, 1932/33), translation shell with double curvature (clinker storage, Beočin, 1933), saw-tooth shell roof with integrated Finsterwalder girder (thread factory, Flurlingen, 1938/39). Other buildings such as the Budapest Market Hall, the Hershey Sports Palace (1936) or the Wythenshawe Bus Garage (1939–42) were essential for the international evolution of shells construction.

The noteworthy knowledge transfer was also not stopped by the Second World War, even if quantities declined with only 65,000 m² of finished shell surface in foreign countries reported to Zeiss between 1940 and 1944. Yet, one has to be aware of the fact that the staggering sum of 775,000 m² shell surface built in the Inland (domestic territory) during the same period also included vast areas covered with Z-D shells in the occupied East-Central Europe. Furthermore, hundreds of thousands of square meters of Z-D shells were built during the war alone in the US. They are not covered by the statistics, since the company Structural Shell Designers Inc., co-founded by Tedesko, had taken over the US patent rights in 1940.

After 1943 also Great Britain was to experience a shell boom based on Zeiss-Dywidag concepts with a couple of more players ploughing the same field besides the official license holder who had been restructured under the name Chisarc and Shell “D” in 1939. Even the Brynmawr Rubber Factory (1946–51) by Ronald S. Jenkins and Ove Arup, the unquestioned flagship of British post-war shell roof production, was heavily indebted to a draft concept presented by Dischinger at the 1930 Liège conference.

The international impact of the Z-D system, although only cursory portrayed in the lines above, should no longer be neglected. Neither was it mainly a theoretical issue put forth by a marginal “German School” nor did it fail to entail any consequences. This point of view, widely shared, rather has to be interpreted as a telling reflection of a widespread disinterest in dealing with structural engineering products that had been generated through a “deductive” approach instead of an “inductive” one (cfr. Kurrer 2012). Hence, it is anything but inexplicable why the aesthetically more pleasing shell designs from the structural artists in the post-war period received a substantially higher degree of attention in the historiography of structural engineering. It is nevertheless surprising that it had to be an architectural historian, Andrew Saint, who insisted on valuing the Dywidag engineers’ work as an essential “search for universalizable forms and solutions to particular problems of applied design”. Being in this respect in high accordance with the core tasks of the engineer’s assignment and having produced a great many results worldwide, the Zeiss-Dywidag system should be granted a second look by construction historians.
REFERENCES

Archival sources

Carl Zeiss Archiv, Jena, BACZ nos. 14758 and 22987.
Fachgebiet Entwerfen und Konstruieren - Massivbau, Technische Universität Berlin, Dischinger papers (DP).

Publications