The Warsaw Daewoo Center nearing topping out.

WARSAW *Trade* TOWER

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As part of its expansion into the newly growing automobile and mobile equipment markets of Eastern Europe, the Daewoo Corporation, based in Seoul, Korea, commissioned the design and construction of a signature headquarters building in Warsaw, Poland. This structure was intended to serve the pragmatic function of providing a home for Daewoo's operations in this new market. Perhaps just as important, its construction symbolizes both the commitment of the capitalist world to the economic development of the former soviet satellites and the continuing success of Poland's conversion to Democracy and free market economics.

Polish Economic and Industrial Background

Poland fell victim to the Nazi aggression near the very beginning of the Second World War. Between the initial Nazi invasion and occupation and the Soviet assault that expelled the Nazi forces toward the end of the war, the city of Warsaw was, for all intents and purposes, razed. Following the end of the War, Poland fell under the control of a Communist government under the direction of the Soviet Union.

The primary focus of this regime, from an economic perspective, was industrialization, rapid reconstruction of Warsaw's essential infrastructure and the satisfaction of basic needs for housing, manufacturing plants and governmental facilities. The absence of significant industrial capacity, combined with the need to quickly rebuild the nation, lead to an early predominance of reinforced concrete construction in the building industry, typical of the eastern bloc nations and of the Soviet Union itself. Simultaneously, however, the Polish ship building industry was nurtured by the new regime, and a large base of skilled welders and other non-building oriented steel workers and steel-manufacturing capacity was developed.

Eventually, this evolved to include production of rolled structural steel,

mostly for export and limited to relatively small sections. The result of all of these trends was an architectural vocabulary in Warsaw that at the end of the Communist era included four basic building types: a limited area of pre-war medieval architecture that was faithfully and lovingly re-built as a tribute to the old city, a few wartime structures left un-repaired as memorials to those who endured or were lost in the War, a few ornate and monumental icons of the Communist society and its philosophies and a tremendous number of generally uninspiring and often poorly constructed communist era apartment and office buildings.

The Architectural Statement

Into this landscape, RTKL proposed to introduce a completely unique architectural statement of Warsaw's transition to a market driven economy and accelerating modernization. That statement takes the form of a 42 story, 184m (604′) tall office tower, springing from a five story retail "podium" centered around an expansive, state of the art display area for Daewoo's automobile line. Below this superstructure, three levels of underground parking were provided to accommodate the tower's tenants and guests. In addition to the shift from the broad podium to the slender tower, the tower itself steps through three major transitions through its height.

The bottom half of the tower utilizes a rectilinear floor plate and stone cladding with a partial semicircular plan element at the north end of the building. From the twenty-fourth to the twenty-eighth floor, the plan remains generally rectangular but shrinks slightly and exposes the southern counterpart of the partial semi-circle below, clad in metal and glass, counterposed against the three other sides, which remain primarily stone. At the 29th floor, the semicircle is exposed further with only a small portion of the lower stone rectilinear plan configuration remaining on the east side of the tower. Finally, above the 36th floor, the metal and glass semicircle is freed, and the rectangular floor plate is abandoned completely.

The Structural Solution

Not surprisingly, the multi-faceted architectural vocabulary of the project lead to an equally varied set of structural components. The three underground levels were constructed of cast in place reinforced concrete. This includes the perimeter walls, constructed by the slurry displacement method, and the horizontal framing, which was a mixture of two-way flat slabs and beam supported one-way slabs. The underground columns in the podium area were also of cast in place reinforced concrete, though the structural steel columns for the tower were continued to the foundation and simply encased in concrete. The low-rise portions of the podium are supported on a 2m (6′-6″) thick soil supported mat foundation, while the office tower rests on a 2m (9′-10″) thick-drilled pier (caisson) supported mat foundation.

The bulk of the superstructure utilizes 6cm (2-3/8″) composite metal deck with 12cm (4-3/4″) normal weight concrete topping (lightweight structural concrete is not readily available in Poland), supported on composite structural steel beams and girders. Although metric deck, shear studs and structural steel shapes were employed, this construction is fundamentally identical to composite steel construction as practiced in the United States. The difficulty faced was that these assemblies had not been used extensively, if at all, in Poland prior to this project. Consequently, the Polish Code did not include provisions for their design. With the assistance of SAP Pro-

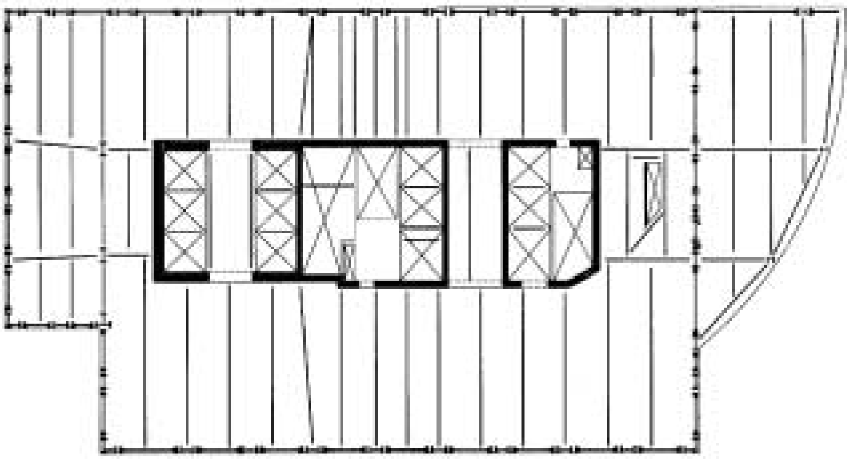

Figure 1: Framed tube and shearwall geometry below level 24.

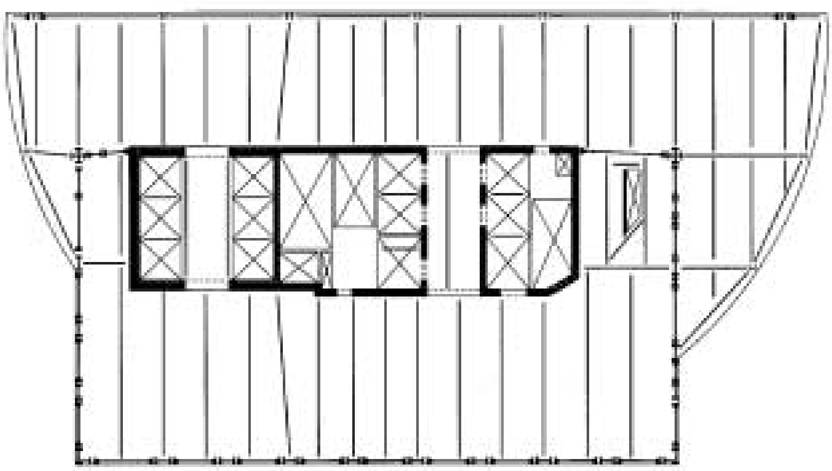

Figure 2: Framed tube and shearwall geometry from level 24 to level 28.

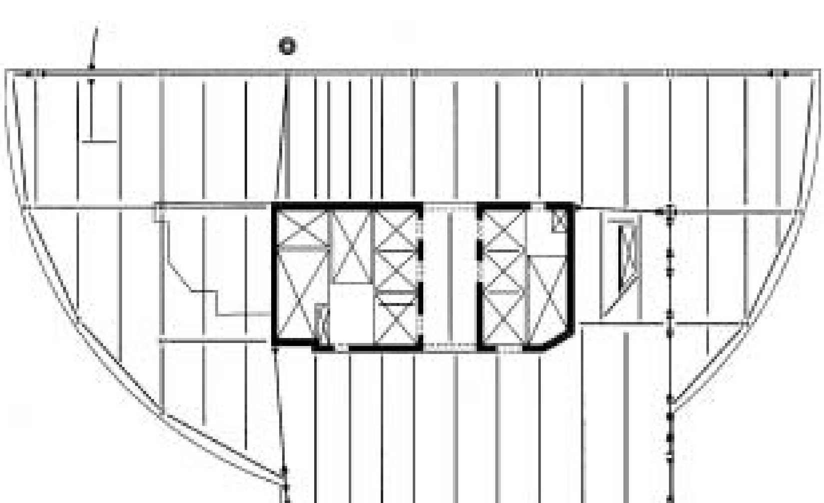

Figure 3: Framed tube and shearwall geometry from level 28 to level 36.

jekt, RTKL's associate Polish Structural Engineering firm, the AISC provisions for composite design were presented to and accepted by the governing Polish code officials for use in the design of the project.

Although there is no record of any seismic activity in Poland, accommodation of lateral load did present a fundamental challenge to the structural design team. Specifically, the wind load provisions of the Polish Building Code are quite adequate for the low- to mid-rise structures that typify the Warsaw landscape and for the consistent and essentially rectangular floorplates utilized on Warsaw's earlier tall buildings. The design team was concerned, however, that the Polish Code's wind load requirements did not adequately address either the height or, more significantly, the irregular and varying profile of the Daewoo Center Project. To address this concern, Rowan, Williams, Davies & Irwin (RWDI) was retained to perform a program of wind tunnel testing and analysis. The results of the testing program yielded base and story shears significantly below the values that would have been dictated by the Polish Code but also identified some torsional and local loading issues that would not have been properly addressed by the provisions of that Code.

Several potential solutions were considered for the lateral load resisting system of the tower. For example, early consideration was given to an outrigger truss system. Ultimately, the extreme concentration of axial loads in the associated "super-columns," combined with the complexity of some of the connections that became necessary to that system, led to its abandonment. After further study, a stepped framed tube system was adopted, hybridized with concrete shearwalls at the office tower core. The concrete walls were used instead of structural steel trusses in response to the general contractor's preference to integrate construction of the core into the foundation construction sequence, schedule the core construction several levels ahead of the leasable floorplate, and once the core

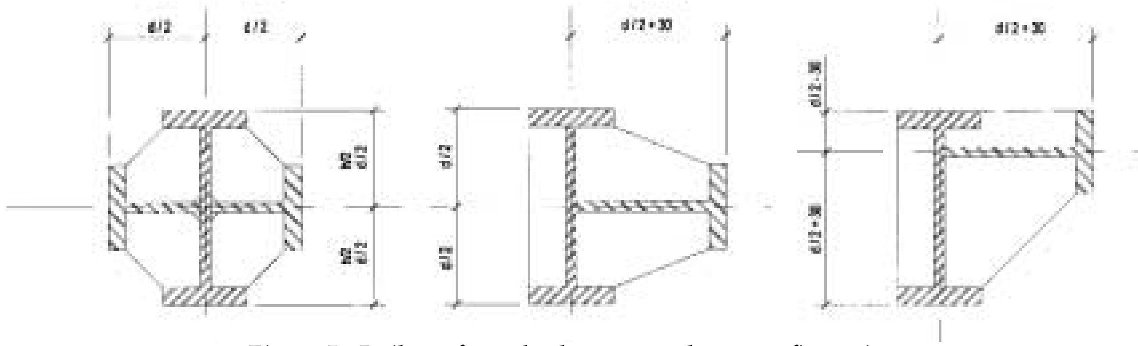

Figure 5: Built up framed tube corner column configurations.

was begun at the underground levels, utilize a flying form system to accelerate construction of the core.

The typical exterior column spacing was set by the architecture at 4.0m (~13'-1"), with some significant variations around the perimeter. This close spacing, in fact, encouraged the selection of the framed tube solution, as it provided the potential for development of a sufficiently stiff tube assembly. At the lowest segment of the tower (up to the 23rd floor), the steel framed tube and reinforced shearwalls act together but as separate structural elements, linked only by the floor diaphragms serving as load distribution elements. This is depicted in Figure 1. Above the first architectural transition (through levels 24 to 28), the width and length of the framed tube are reduced, and the west side of the tube comes into alignment with the west side of the concrete core. Through these levels, the concrete core becomes an integral component of the framed tube, essentially forming a very large-scale composite beam-column. This configuration is shown in Figure 2. A third step in the framed tube occurs at the 29th floor, where more of the emerging semicircular upper tower segment is exposed, and the framed tube at the south face retreats to the south end of the core shearwall structure. This final framed tube configuration is shown in Figure 3 and continues through the 36th floor, above which the framed tube is eliminated and the wind load on the now semi-circular, upper portion of the tower is resisted entirely by the reinforced concrete shearwalls of the office core, as shown in Figure 4.

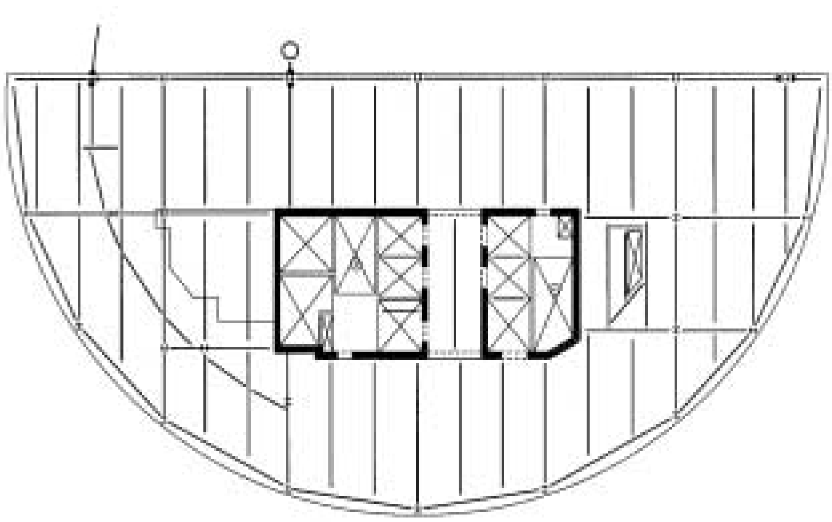

Figure 4: Shearwall geometry above level 36.

As discussed earlier, Polish production of rolled structural steel shapes is limited to relatively light sections. Fortunately, a great number of structural shapes are manufactured in Germany, Belgium and other parts of Western Europe. These shapes, although different in many specifics from those documented in the AISC Steel Construction manuals, cover the entire strength and stiffness range of that familiar "menu".

The principal software used for structural design of the Warsaw Trade Tower was the RAMAnalysis package (the precursor to today's RAM Structural System). Within this software, the design team was able to create custom tables of section properties to include AISC standard shapes that are rolled either in Poland or other parts of Europe (for example, by TradeARBED), non-AISC shapes from Polish and other European facilities and the heavy fabricated corner column shapes required by the framed tube system, discussed in more detail below. Beyond this straightforward use of the RAM-Analysis custom table feature, the team also adjusted the optimization process to favor sections produced in Poland. This was done by assessing a cost premium to non-Polish shapes to account for their higher cost (per tonne) relative to material rolled in Poland and altering the normally weight based selection order in RAMAnalysis to reflect that system of premiums.

To successfully affect the framed tube lateral system, the close column spacing had to be coupled with very stiff column and beam sections. This was necessary to address both the required overall stiffness of the framed tube and mitigate the shear lag phenomenon typical of framed tube construction. Despite these measures, shear lag did, as is also typical, lead to a concentration of wind generated axial load in the corner columns of the framed tube. Additionally, these columns were subject to significant flexural loads to both axes, both individually as a result of loads along the principal axes of the tube, and simultaneously under combined, or torsional, wind load conditions. To address these particular issues, the framed tube corner columns were designed as built up cruciform shapes, utilizing a single "wide flange" coupled with "tees," typically split from the same section size as the wide flange. The varying location of the framed tube system within the overall floorplate of the building, however, required that these built-up shapes be asymmetrical at most locations. The locations of the various configurations are apparent in Figures 1 through 4, and the specifics of their assembly are shown in Figure 5. These assemblies provided a very efficient technique of both building up cross sectional area and "weak axis" stiffness to address axial load and of providing excellent flexural capacity in both axes.

The Project offered many unique challenges to the entire Project Team. RTKL and its associate Polish Architectural and Structural Engineering Consultants (MWH Architekci and SAP Projekt, respectively) were faced with translating the expectations of an international client and the requirements of many locally unfamiliar design and construction techniques into bi-lingual construction documents that were usable to both Bovis Polska (the internationally based general contractor) and local subcontractors, including the Warsaw based structural steel contractor, Mostostal Warszawa. The project team ably met this problem, in addition to all of the "normal" puzzles that are part of a project of this size and complexity, and the ancient city of Warsaw entered the 21st century with a bold new landmark and icon of a bright future.

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ARCHITECT:
MWH Architekci, RTKL's Associate Polish Architectural Firm, Warsaw, Poland

GENERAL CONTRACTOR:
Bovis Polska, Warsaw, Poland (a subsidiary of Bovis International, London, United Kingdom)

SOFTWARE:
RAMAnalysis