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EXPERIENCE Music Project

Seattle, Washington

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Called "eye-poppingly spectacular" and "frozen music," the free-form swoops and curves of Paul Allen's 140,000 sq. ft. Experience Music Project (EMP), an interactive music museum, define a new standard of creativity. Yet it was the development of an entirely new structural system and the creation of the project in total 3D that really positions EMP at the forefront of engineering technology.

To truly comprehend the level of effort and innovation required, it is first necessary to understand the evolution of the project. Paul Allen, Microsoft's co-founder, and his sister Jody Patton (EMP's executive director), were devoted to creating a facility dedicated to the history of rock and roll. The original concept was a small tenant improvement in an existing one-story building on the grounds of the Seattle Center (home of the 1962 World's Fair). However, it quickly became apparent that Allen's vision was on a much grander scale. He and Patton established the building program and then charged renowned architect Frank O. Gehry with taking the project into uncharted artistic realms.

Using a series of block and massing models, Gehry first determined positioning on the site and the basic spatial and functional concept. Then, starting with sketched visions and proceeding to carefully crafted hand-built models, Gehry's office created the look and feel of EMP. Once satisfied, a digitizing tool captured the model's geometric coordinates into sophisticated 3D software. Visually refined, it now remained to figure out how the structure could be built.

While Gehry's Bilbao Guggenheim project looks similar to EMP, it is comprised primarily of "ruled surfaces." This means that the structures can be framed conventionally with straight members and the skin warped to fit the design intent. EMP's constantly changing curvature in all directions prevented this approach. Yet the project's success rested on the development of a structural system with a defined load path that was able to adapt to the curves, span long distances, resist earthquakes and, of course, be constructable.

Ultimately, after exploring many different structural concepts, close examination of Gehry's vision revealed an almost "organic" formation, with each of the six building elements having an axis and orientation resembling "spines." This led to the idea of drawing upon the human form, with the

torso shaped by a skeleton of ribs covered by skin, similar to building techniques used in the aviation and boat-building industries. The solution had been found in an approach utilizing continuously curving ribs and a skin.

This totally new structural system incorporates 240 individually curving steel beams, covered by mesh, then a 5″ layer of shotcrete over welded wire fabric. This creates each major gallery element as a steel-stiffened concrete shell, with the shell resisting earthquake forces while it is held in place, shaped and stiffened by the steel ribs. The entire structure was then coated with a waterproofing membrane. An elaborate system of 5″ diameter steel pedestals of varying lengths attached to the ribs, to support 3,000 panels of steel and aluminum skin (comprised of 21,000 individually shaped shingles).

How the Structure Satisfies the Program/Unique and Innovative Characteristics

It is a indisputable that steel was the key to the engineering solution used to create EMP. No other system examined provided the flexibility, precision, strength and artistic freedom of steel. The following discussion highlights some of the unique challenges and innovative solutions that went into developing the steel system used for EMP:

Complex Invention of "Steel-Stiffened Concrete Shell" Structural System

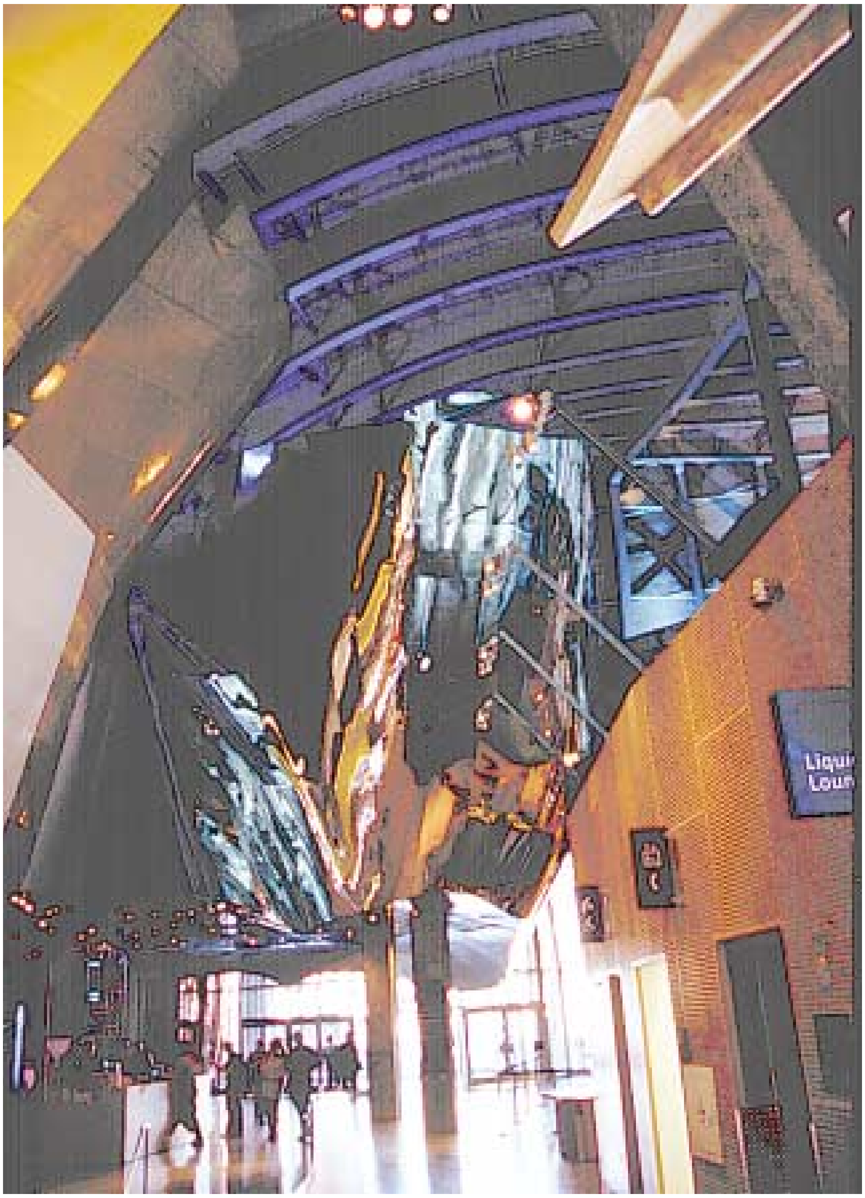
A new structural system had to be invented for the free-form visions of Paul Allen and Frank Gehry to become reality. The system had to accommodate EMP's non-symmetrical curvature in all directions.

As various ideas were suggested, it was necessary to analyze them conceptually through how the system would be built to determine feasibility. A number of different concepts were tracked at the same time, and often ideas that had been developed at length would ultimately be rejected. Complicating matters even further, this development of the structural system was undertaken at a time when the nature and material type to be used for the building's skin had not yet been determined.

The ultimate solution, combining steel ribs, a composite concrete shell, and a pedestal support system, was totally unique. Taking its cue from the ribbed construction of airplanes and boats, the idea was applied for the first time ever to a building. By designing each rib with a different geometry, the desired curves and swoops could be captured in place. The steel-stiffened rib system provides the design profession with a new tool in creating what in the past could only be dreamt about.

Advanced Application of Computer Technology Ever

On a typical project, there is no connection between the databases of information used for design and construction; everything is accomplished with two-dimensional drawings. The approach on EMP was groundbreaking: everything was accomplished using one common database. Starting with a hand-created small-scale model and a digitizing tool and continuing through to the comput-



ers that ultimately cut the final steel shapes, the entire creation of EMP was accomplished through a series of computer "handshakes." The geometric data was initially captured in CATIA, a 3D solid-modeling program. The geometry was tested visually on workstation computer screens and physically through the creation of computer-cut models to confirm that it matched Gehry's intent. That information then became the database for all geometrical control on the project, exchanged electronically from computer to computer, ensuring continuity and facilitating communication of vital information to all team members, including the contractors. While buildings have previously been designed in 3D, never before has the approach been used in such detail to actually construct a building. The geometric data and model were specifically used in the structure to:

- Provide virtual walk-throughs;
- Perform interference checks;
- Calculate quantity take-offs;
- Perform steel detailing;
- Cut the components of the steel ribs;
- Provide dimensions;
- Set the concrete formwork and embeds;

Define survey points.The project development and execution was so complex that a master flow chart was created early on by architect, contractor and structural engineer to detail the upcoming computer handoffs and required technology. The 28-step chart graphically detailed the programs and interfaces required for execution, so that all team members could ensure that they were technologically prepared to participate.

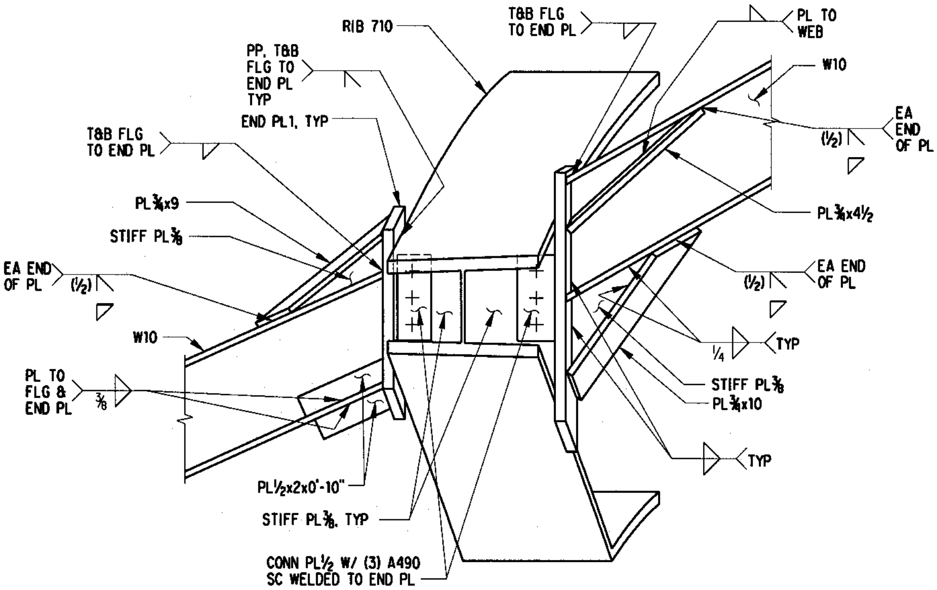
Engineering Revisited and Modified Every Aspect of Design

While some projects require the development of a single new method or technique, EMP demanded that every single aspect of its structure be invented. This included how the structure was analyzed and designed, how it was shown on the drawings, how it was detailed, how it was erected, how the concrete was formed, placed and finished, etc. Full-scale mock-ups were employed by the project team to test and refine many of these new techniques.

Many of the concepts used for EMP incorporated existing technologies borrowed and enhanced from other disciplines:

- The steel rib system was developed from bridge technology and girder fabrication methods, pushed to the extreme.
- Shape-fitting programs were employed to minimize material quantities by analyzing the "best fit" of multiple curved ribs from a single plate.
- The composite action of the steel ribs and shotcrete shell emulates unibody construction used in the automobile industry.
- The shotcrete shell shot on fine wire mesh was adapted from rock formations in zoo displays.

Even the usually routine parts of design had to be completely rethought. For example, many code provisions define requirements in terms of "wall systems" and "roof systems." When you look at EMP, it is impossible to determine what is a roof and what is a wall. The roof plan for the EMP building is actually a contour map, with ridges and valleys, not unlike what you would see depicting a mountain range. Routine structural/mechanical coordination items, such as sprinkler lines, took on a whole new complexity when dealing with curved three-dimensional spaces. "No one has built anything like this before," says Paul Zumwalt, EMP owner's representative, "It's essentially a piece of modern sculpture that holds people and meets code."



New Technology = Increased Control

The computerized technology and hand-offs used on EMP produced a phenomenal level of control: e.g., the steel fit-up on the project was better than on a conventional building, even though the design was incredibly more complicated. Application of these technologies to conventional building design will bring about a giant leap forward for the industry. Increased control can produce higher fabrication accuracies, faster erection times, increased efficiencies on takeoffs and materials quantities and 100% coordination between disciplines (using visualization tools that allow the building to be built in virtual space).

Extremely Strict Tolerances

The very nature of EMP's structure dictated a series of tolerances that were phenomenally strict:

- A sequential analysis of the shotcrete application was performed to analyze the deflected shapes and determine the optimum approach to meet overall building tolerances;
- The geometries of each and every rib had to be smoothed and adjusted based on what could be fabricated from a curvature standpoint;
- Ribs were placed every 10′ perpendicular to the each element's "spine" due to the limitations of the load-carrying capacity of the shotcrete mesh;
- The steel ribs were set using 3D laser technology to confirm location and ensure tolerances;
- The size of each individual skin "shingle" was determined through a program that analyzed the buckling capacity of the chosen skin material when warped in two directions

Geometric Irregularities = Increased Complexity

The geometric irregularity of EMP caused a tremendous increase in the complexity of the design. One example is the computer earthquake simulations performed to determine the required strength and stiffness of the structure. Developing the computer model for a 50-story office building would typically take about one week, with each analysis run lasting 20 minutes. Comparatively, developing the computer model for the EMP structure took three months, with each run lasting over 24 hours.

Skin Options Analyzed at Length

Obviously, skin options had to be examined not just from a fabrication point of view but also for loading, attachment to the structure, affect on system performance, etc. Options examined were numerous and included a composite concrete-and-terrazzo system shaped with a five-axis milling machine (commonly used to shape the hulls of custom boats), a cast-in-place solution, a fish-scale-like glass system and titanium. The system selected utilizes panels of painted aluminum and interference-treated stainless steel (a process that interferes with the natural reflection of the spectrum of light, absorbing selected wavelengths and reflecting the desired color).

Seismic Complexity

Seattle is in the fourth most hazardous of the five zones identified in the Uniform Building Code. Every aspect of the design needed to address this challenge.

Creating the Future of Building Design and Construction

One of the biggest steps forward on EMP was the level of integration between the computer geometry database and the actual manufacture of the building components. For example, take the creation of the steel ribs, all done with computer-controlled processes. Basically, the steel was literally shaped by the architect's hand, as the original physical model was preserved through a series of electronic "baton passes."

This approach is the way of the future. Ten years ago, CAD was something new and almost experimental. Three-dimensional documentation, such as CATIA, is currently thought to be at the same stage. Yet 3D building design—from start to finish—is the future of the industry. It may be another five or 10 years until it is widely accepted, but the project benefits to be gained by all are amazing: advanced integration, increased team communication and coordination, more accurate takeoffs and estimates, better cost estimating, etc. Every single team member on this project was a pioneer and at the same time a "guinea pig": thought processes had to be modified, new equipment and software developed and problems overcome with this entirely new way of design. While the result, EMP, is certainly thought provoking, the approach itself is pioneering, leading the way for others in the future of building design. In fact, EMP has been hailed as "benchmark architecture for the millennium."

Meeting the Owner's Expectations

Budget, Schedule, and Program Meet Owner's Expectations

It is very difficult to characterize the budget and schedule for EMP, because they remained moving targets dictated solely by the owner's desires. The program was continually expanded, both in terms of content and ambitions. Starting out as a $6 million tenant improvement project, the project evolved, at the owner's request, to a $240 million facility. Yet, the structural solution was key to the building's creation, and throughout the process, the system was developed with a focus on both cost and feasibility. While the owner deferred to the architect in terms of design, they had strict expectations for the program space. All of these program requirements were met.

Owner and Client Intimately Involved Throughout Project

It would have been virtually impossible to create this facility without the intimate involvement of the client and owner. Per Paul Zumwalt, the Owner's Representative, "The daily heroic effort that SWMB performed in the design and construction management phases are what truly stand out."

Social and Economic Considerations

The owner wanted to create this facility as much for the public as for him. He wanted to allow others to experience the mind- and future-expanding properties of music that had affected him so dramatically as a youth. As such, the "owner's expectations" very much included a number of social and economic considerations. The new structural system developed was absolutely critical to the successful creation of EMP. Without this key component, it is unlikely the facility would have moved forward, and certainly not with its present configuration or impact. Some of the social and economic benefits include:

- Adding music to learning experience for schoolchildren nationwide
- A nonprofit organization, EMP is developing curriculum for teachers in Seattle and nationwide. The purpose of the curriculum will be to expose children to music and the arts at a young age.
- Providing hands-on exposure to the latest in technology
- Interactive exhibits allow visitors to experiment with tools and techniques available to the general public only through the EMP experience.

Exposing the Pacific Northwest to leading-edge architecture

Frank Gehry has an international reputation, drawing visitors from around the world to view his creations, such as the Guggenheim in Spain. EMP gives residents and visitors to the Pacific Northwest the unique opportunity of experiencing first-hand the work and artistry of this world-renown architect.

The "Seattle Center" was built for the 1962 World's Fair and has been used since then for a variety of cultural and entertainment purposes. The creation of EMP at the Center has revitalized the aging locale and provided the area with a new focus as the artistic center of the City.

EMP is expected to attract 800,000 visitors per year, with corresponding revenues to merchants and the city (from hotels, meals, shopping, etc.). The facility provides 620 jobs for local residents. The facility also generates $301,000 a year for the city of Seattle, paid for the next 40 years as a land lease.

Paul Allen set out to create a state-of-the-art facility that would provide inspiration, provoke thought, offer hands-on exposure to cutting-edge technologies and celebrate musical innovation.

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GENERAL CONTRACTOR:
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FABRICATOR:
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ERECTOR:
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DETAILER:
Angle Detailing, Inc., Wilsonville, OR

SOFTWARE:
CATIA