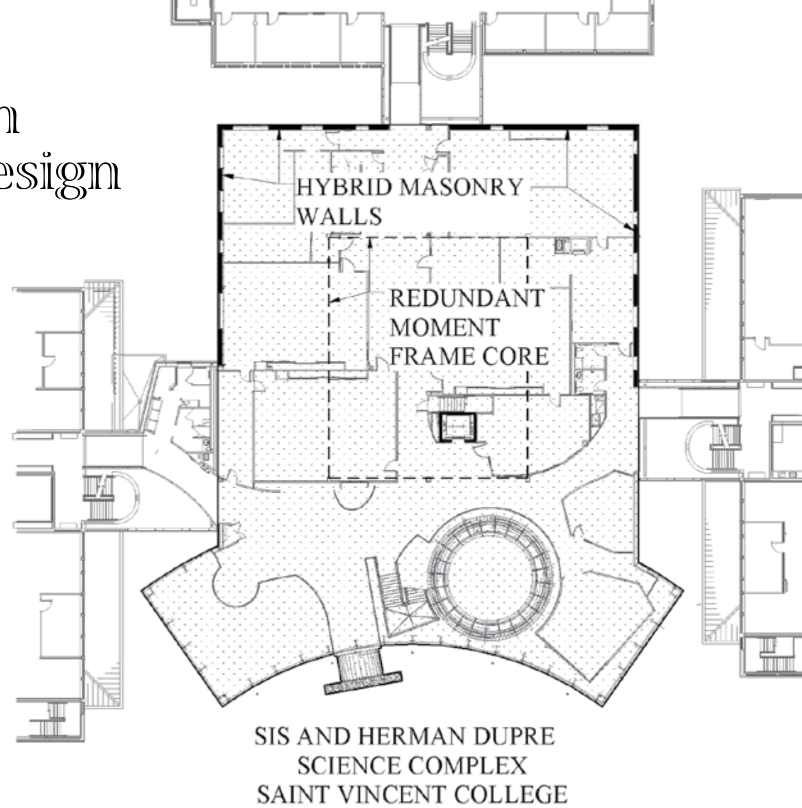
Science Complex Grows With Hybrid Masonry and Steel Design

By Erik R. Majcher, S.E., P.E.



As the new gateway to the St. Vincent College campus, Latrobe, Pennsylvania, the owners of the Sis and Herman Dupre Science Complex, as well as the Architects MacLachlan, Cornelius, & Filoni, wanted to make a grand gesture to the public and students as it welcomes them to campus. Situated on the top of a slight hill, the first part of the new building incorporates a large, two-story steel space truss and glass atrium that has a subtle and modern resemblance to St. Peters Cathedral in Rome. The large atrium, approximately 8,000 square feet in plan, gently begins to embrace and wrap around as you pass through a brick archway into the otherwise glass facade. Once you have passed through the atrium, you come to a more orthogonal layout that plays well with the typical steel framed structure. This portion of the building, approximately 13,000 square feet and almost square, includes a basement for mechanical units, two levels dedicated to labs and classrooms, and finally a mechanical penthouse capped with a tiered hip roof. This portion of the science center includes a stoutly brick and masonry exterior wall system. The wall structure was originally planned to be a simple infill wall supported on a grid of structural steel. However, given the wall sections anatomy it was an opportunity to use a more efficient hybrid design of steel and masonry.

Combining steel and masonry has been standard in construction since the introduction of steel framed structures. Buildings were often "designed" with a steel gravity system, then in-filled with masonry to provide lateral support. Due to the typical designs of the era, and the lack of a comprehensive building code among other things, standard building design typically included abundant masonry walls with small punched openings that would act to resist lateral forces. Because of the abundance of walls and generally short and squat shape, the adequacy of the lateral system was rarely a concern. Efficiency was achieved as both systems were being used to support the structure.

Due to a number of changes to the building and design industry, including buildings with more open designs, tighter construction sequencing, building codes which did not include hybrid design and the advancement of engineering software that did not incorporate the more complicated process of hybrid design, the practice became less prevalent. Therefore, buildings were efficiently produced in regard to how quickly they were engineered and erected, but lacked a material efficiency. Given the aesthetic intent and simple grid layout of this building, the common method would have been to design the steel frame to support all gravity and lateral loads and simply consider the masonry system as additional dead load on the perimeter beams and foundations. Given strict code required deflection limits for beams supporting masonry and relatively large beam spans, a heavy penalty would have been put on these beams creating a very conservative and inefficient design. This inefficiency was realized and it was decided to use a better method.

Figure 1: Construction photo.

Design Method

The efficiency of the hybrid masonry design comes from the ability of the masonry system to support a portion of the gravity and lateral loads instead of relying solely on the steel frame to support those loads, in addition to the loads from the masonry wall, thus giving lighter steel sections. Since the steel frame is in place first, but the building does not experience full design live loads or full lateral loads, it was analyzed for a series of load cases developed for the various stages of construction and the loads it would have to support. The loads were developed from seismic design category C loading requirements and 90 mph wind loads. The design of the building, per the 2003 *International Building Code* (IBC), was governed by seismic loads.

During the schematic design of the Science Center, a design was created that was based on the conventional method of framing supporting all the loads, including the masonry walls, to develop a "worst-case" scenario regarding beam and column sizing for preliminary estimating and also as an in-house comparison to study the material efficiencies. The actual design, however, included using in-house spreadsheets in addition to the masonry wall module in RAM Elements by Bentley to analyze the system. The in-house system was used to verify the design produced by the new software. Once the analytical model was built, the information from that model was used to perform the designs of the masonry and steel.

Figure 2: Construction photo.

Hybrid masonry design has six different ways that loads can be transferred from the steel framing to the masonry wall. They include:

1) Type I – Shear at Beam
2) Type II Regular – Axial Load and Shear at Beam
3) Type II Compression Only – Axial Load at Beam
4) Type III Regular – Axial Load plus Shear at Beam and Shear at Column
5) Type III Compression Only – Axial Load, Shear at Beam and Shear at Column
6) Out Of Plane Only

There are a number of factors that direct a designer to a particular system. A full description of the systems and factors that direct this decision are not in this article (refer to *Hybrid Masonry Structures*, D.T. Biggs, 10th North American Masonry Conference, 2007, The Masonry Society for a description of the types and load transfer). For this project a Type II Regular system was chosen. Once the software design had been completed, the design was checked with the in-house developed spreadsheets which showed similar reinforcing requirements. Since the software does not develop connection details, the transfer of loads between the beams and walls were separately analyzed and designed. Details to accommodate the architecture were designed and drafted after the wall and frame design were completed.

Given the multiple analyses required, it became a much more labor intensive task to design the hybrid system. And, after the hybrid design process, first with the help of software and next with spreadsheets, it is easy to see how the development of technology that was unable to design this type of system contributed to the lack of use of hybrid design. As engineers began to rely on technology more frequently, it obviously became a much simpler task to ignore the ability of the masonry system and simply provide a steel design.

Design and Construction Considerations

Given the typical modern construction sequencing, which means the steel frame, including concrete slabs and metal deck are in place often before masonry construction has begun, there are a number of considerations that must be included in the design.

Lateral Bracing During Erection

In the case where the entire lateral system is accounted for in the masonry system, there is a need for lateral bracing during erection. While this could be considered a means and methods requirement for the contractor to meet, it is an opportunity for the designer to provide a level of redundancy in the design, which may be required depending on the code requirements. Given the tiered hip roof system of the building, it was necessary to include a steel lateral system for the mezzanine level of the building. Once below this level, the steel frame and composite deck could have been designed to transmit the lateral forces to the exterior masonry walls, but given the concern for sequencing it was decided to extend the lateral system to the foundations. Therefore, a set of simple moment frames were designed around the interior circulation core of the building to provide the lateral stability during construction, and as a redundant system.

Masonry Reinforcing and Steel Connections

Since the steel framing system is typically in line with the concrete masonry wall, and the steel system is in place when the masonry wall is constructed, a system must be created to allow reinforcing to be accurately placed throughout the height of the wall and for grouting of the masonry cores. Additionally the designer must consider the transfer of forces between the steel frame and the masonry wall. In this project, perimeter beams with a uniform depth were chosen to meet window opening requirements and provide a sufficient gap between the bottom of the beams, masonry coursing and a continuous bond beam so that reinforcing could be inserted and grout could be placed into the wall. Additionally, masonry units were required to be knocked-out at certain locations to make sure the reinforcing was properly located within the masonry wall. To accomplish the shear transfer of forces from the steel frame to the masonry wall, a series of W8 beams, 8 inches long are spaced along the bottom of the beam (*Figures 1* and *2*). This allows the bond beam masonry unit to be set and slid into position when necessary. These beam segments reach into the grouted bond beam and provide the shear transfer between the steel frame and masonry wall. Additionally, grout is continually packed between the beam and masonry wall below.

Beam Deflection

Due to the relatively light beam sections that the design produces, there is a strong potential for beam deflections to be excessive. Therefore, the deflection of the beams needs to be checked against the various loading that the beams will be exposed to before they are supported by the masonry. Often, temporary support of the beams will be necessary until the masonry wall is in place.

Results

After completing various analyses and comparing the hybrid masonry design to the original system of steel moment frames, a savings in steel weight at the perimeter wall of approximately 23% was achieved. This savings does not include the additional fabrication costs of the moment connections. Considering the detailing required to transmit forces from the frame to the wall, the costs would be approximately equal. Future designs won't always require redundant systems and moment frames, thereby enhancing the economy of the hybrid masonry system with structural steel.▪

Erik Majcher, S.E., P.E. is the Vice President of Robert Darvas Associates, P.C. and acts as the managing partner. Erik may be reached at ***emajcher@robertdarvas.com****.*