# Innovative Design Cuts Costs

## The use of composite construction with partially restrained connections reduced framing costs on a 34,000-sq.-ft. retail building by 27.4%

*At first glance, the new Mt. Kisco Furniture Store in Mt. Kisco, NY, looks like most of the other nearby structures. Closer examination, however, reveals an innovative structural system that minimizes material use.*

Up until October 1990, the Mt. Kisco Furniture Store was a thriving retail establishment in downtown Mt. Kisco, NY. Then tragedy struck in the form of a raging fire that destroyed the structure. The owners, the Saroken family, moved quickly to replace the building which had long housed the family business.

"The owners wanted the replacement building to fit into the context of the community, but they also wanted the best looking building on the block," according to Kenneth Nadler, a principal with Nadler Philopena Architects. "We photographed the entire street and our design tries to pick up the scale and proportion of the nearby properties." The result is a limestone facade with classic features such as brass light fixtures. "We wanted the structure to be reminiscent of a turn-of-the-century cast iron building, but with modern touches," he explained. The two-story building houses a Gap store on the first floor and the family furniture business on the second.

But while the architectural design of the building is traditional, the structural design is thoroughly modern.

Typically, a small 34,000-sq.-ft. (3160 $m^2$), two-story retail store would be designed with simply supported girders. Instead, the engineer, N. Wexler Consulting Engineers, New York City, decided to use composite girders with partially restrained connections (Wexler calls his design a Restrained Girder System, or RGS).

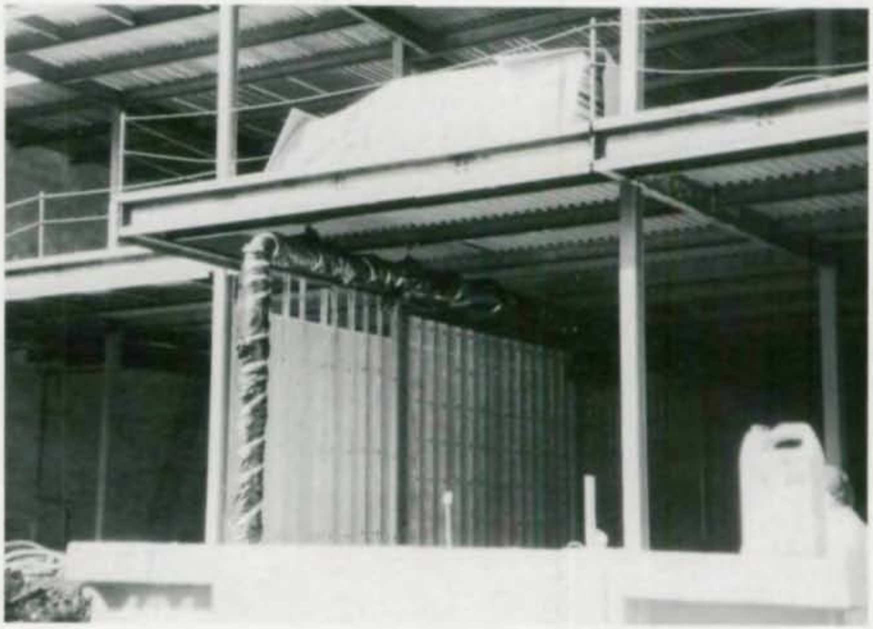
The reason for the design, according to Neil Wexler, P.E., was economics. "Simply supported girders would have been W14x34; with restrained girders, only W14x22 were required," he explained. "The entire project used only 76 tons (68950 kg) of structural steel, resulting in about 4.5 lbs. of steel per sq. ft. (22 kg/m$^2$)—a very efficient structure."

Wexler has been working with composite girders and partially restrained connections for several years and has recently begun giving presentations on the subject.

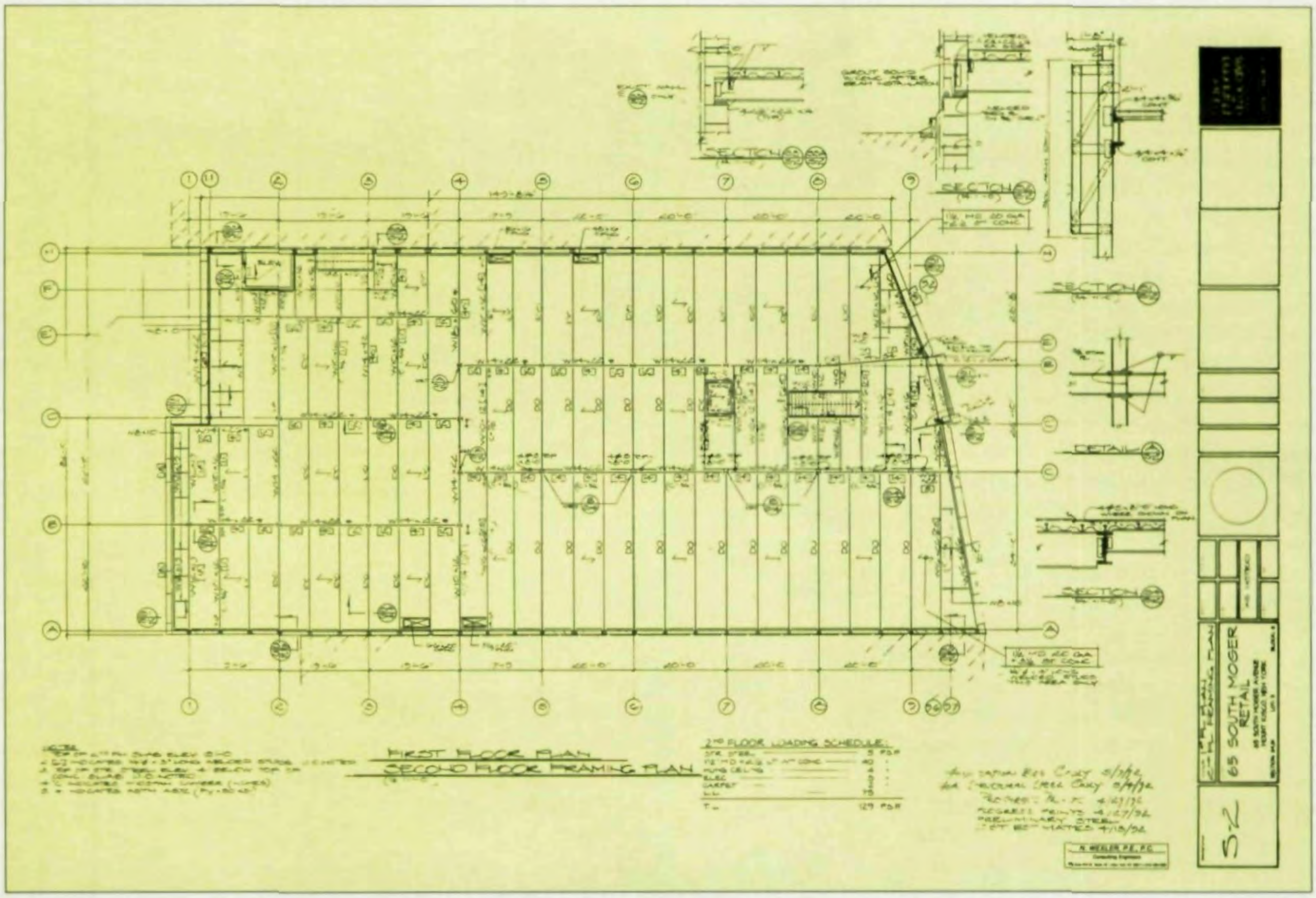
"The traditional design for buildings with steel frames is based on composite girders with simple connections," Wexler writes. "The disadvantage of this traditional design is that the entire moment requirement is at one portion of the girder, resulting in large size girders. Also, girders have large mid-span deflections during construction, when the concrete is wet. In order to eliminate these disadvantages, the designer specified camber or temporary shoring. However, since both of these methods are costly and difficult to implement, contractors often preferred to do without them and instead increased girder sizes even further. With partial restraint connections, girder sizes can be decreased and deflections reduced."

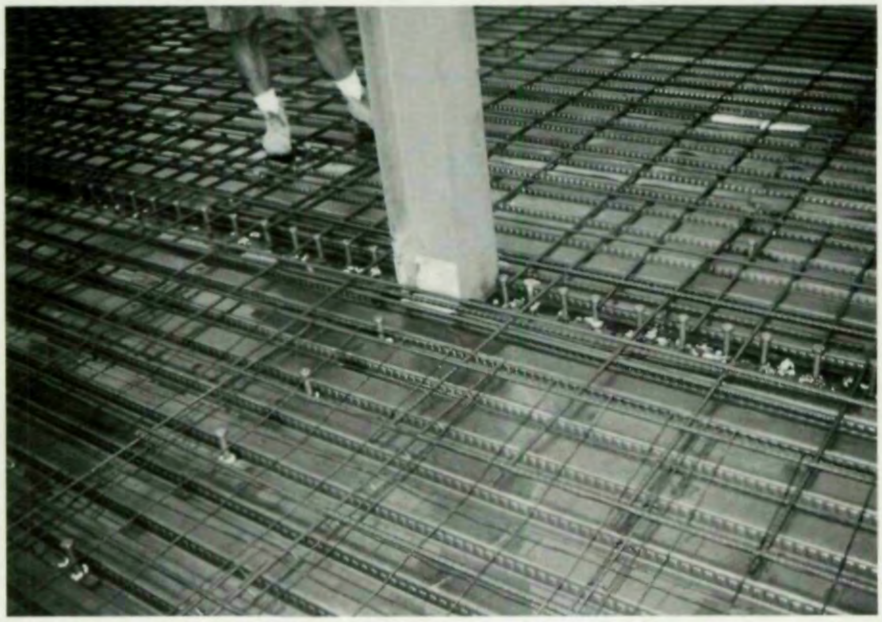
With RGS, two different restraint types are possible, according to Wexler. "When deflections during construction are large, and/or the girder sizes are governed by construction loads, girder-to-column moment connections are preferred. When deflections do not govern, and the girder size is governed by superimposed loads, negative concrete reinforcement bars are preferred." Due to the small calculated deflections during construction, only concrete reinforcement was used for the Mt. Kisco Furniture Store project.

As with composite construction with simple connections, the design of a partially restrained system is done in two phases—a construction phase when the concrete




*By using composite construction with partially restrained connections, the project's designer reduced the typical girder size from W14x34 to W14x22. The RGS design also reduced the number of studs required, though it did require the member to be cambered.*



is wet and a final phase after the concrete hardens.

During the construction phase, the steel girder alone supports all the loads. "Some steel girders with simple connections have significant mid-span deflections at this phase," Wexler explained. "Introducing moment connections results in reduced mid-span deflections." The reduction can be dramatic. For a beam with fixed connections, the mid-span deflections can be reduced by as much as 58% if only one end is fixed and by 80% if both ends are fixed.

"To provide the rigidity required for this phase, the end moment connection must be designed as a rigid connection (AISC ASD Type 1 Construction)," he added. "During this phase all connection components are stressed elastically. The connection is strong enough to hold the original angles between members unchanged, reducing the mid-span moment and deflections.

During the final phase, the steel girder acts compositely with the concrete. "Once the concrete hardens, superimposed loads such as partitions, mechanical, ceiling and live loads are applied. At this time, the moment at the girder end wants to increase. This increased end moment is restrained by the couple produced by negative concrete reinforcement and the girder bottom flange. When the connection has reached its elastic capacity, it will deform plastically," according to Wexler. "All excess moment "shaken off" by the semi-rigid moment connection is now transferred to the middle section of the girder. Since this middle section is composite with the concrete, it is both strong and rigid. Therefore, any deflections associated with the final phase are small."

Wexler does caution that the design engineer must investigate for each individual project the sensitivity of the system to deflections when the concrete is wet. In some cases, the engineer will need to give recommendations for the concrete pour sequence and the acceptable locations of construction joints.

### End Moment Connections

For moderate size moments, Wexler uses an end plate type connection. "It performs well as a rigid connection during the construction phase and as a semi-rigid connection during the final phase," he explained. "An end plate is a particularly good choice because not only does it deliver forces to the column but it also reinforces the column by spreading compression forces over larger areas, just like a bearing plate, thus reducing the need for compression column stiffeners. It is especially economical when full penetration welds are not required."

Another acceptable connection, according to Wexler, are top and bottom angles. "Angles are a good choice because the bottom flange is reinforced against local buckling by the horizontal leg of the angle." For this project, an L8x4x½ was used to enure that the girder bottom flange bears against the column. The project utilized 2½" (64 mm) of light weight concrete poured over 1½" (38 mm) metal deck. At one location, where the span is 34′ (10.4 m), the concrete thickness was increased to 5" (127 mm) in order to decrease floor vibrations. Bay sizes are typically 23′ x 23′ (7.01 m x 7.01 m).

Increasing the connection size beyond that required for full fixity during the construction phase is unnecessary. One way to evaluate a girder with moment connection is by making use of moment connection rotation curves. "With RGS, a composite girder with partial restraint behaves just like a steel girder with full restraint when the concrete is wet," according to Wexler. "After the concrete hardens, and additional loads are superimposed, the connection provides additional restraint until yielding of the reinforcement bars; then the girder behaves just like a simple supported composite girder."

### Additional Restraint

Research done at Queens University in Kingston, Ontario (Canada) by Professors Karl Van Dalen and Hernan Godoy reveals that additional moment strength can be achieved at the beam column connection if only 0.46% of the concrete slab area is provided as slab reinforcement, reports Wexler. "This additional strength is at least equal to the ultimate moment capacity of the composite beam and is not influenced by the type of connection between the steel elements. The rotational capacity of the composite beam-column connection also is at least equal to that of a conventional, non-composite rigid steel connection.

Wexler adds that the AISC *Manual of Steel Construction (LRFD)* allows calculations of the negative design moment strength based on plastic stress distribution of the composite section provided that the following are met:

- Shear connectors are located in the negative moment region.
- The slab reinforcement is adequately developed.
- The steel beam is compact and braced.

"The designer can use this additional strength to reduce the girder size further," Wexler said. "Only additional studs and negative concrete reinforcement are needed." He does caution, however, that Van Dalen's research shows that in order to ensure a uniform cracking pattern in the slab in the vicinity of the column that at least twice the minimum area of steel reinforcement be extended on each side of the column centerline.

### Other Considerations

**Unbalanced loads:** While unbalanced loads might overstress non-composite steel girders with partial restraint, this is not the case with composite girders for most common buildings as long as adequate concrete reinforcement is provided.

**Ductility:** Ductility is associated with the ability of the joint to rotate after yielding. Joint rotation can be prevented by premature local or overall buckling of the bottom flange and buckling of the web. The use of under-reinforced sections assures adequate post-yielding rotations, Wexler stated.

**Composite Studs:** Stud design criteria is similar to composite girders without restraint with the exception that if top reinforcement is used for restraint then additional studs are required between the point of maximum negative moment and point of zero moment. "The number of such studs shall be selected to develop the negative moment," Wexler said.

### Cost Savings

The cost savings on the Mt. Kisco project were dramatic. With simple supported girders, the project would have used A36 W14x34 girders with no camber and no rebars and 40 studs. Wexler reports that in the New York City area, the 20′ girder plus the 40 studs would cost approximately $610 (on projects outside of New York City, Wexler has paid as little as $450).

The composite system with partially restrained connections, however, required A36 W14x22 members with ¾" (19 mm) camber, four #5x8′ long rebars and 34 studs. The cost in New York City for the 20′ (6.09 m) girder, camber, rebars and studs is approximately $443 (outside of New York City, about $328), for a savings of $167 per member, or more than 27% compared with other design methods.