Cable Stayed Cathedral Ceiling

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ABSTRACT:

Converting an existing, conventionally framed roof and ceiling into a cathedral ceiling presents many design and construction challenges that can be solved with the use of cable stayed structures. Architects and Engineers are often asked to modernize older buildings. Cathedral ceilings are a common feature to many new homes in the United States. A cathedral ceiling provides a large, light airy space that people often want replicated in older houses.

The structural integrity of the building will be compromised if ceiling joists are simply removed to create a cathedral ceiling. However, installation of new cable stayed structures allow the removal of the ceiling joists and provide an effective method to modernize an older residence with a new cathedral ceiling. One of the primary differences between a cathedral ceiling and a conventional ceiling is the removal of the ceiling joists. Cathedral ceilings eliminate conventional ceiling joists and as a result, the cathedral ceiling must rely on reinforced walls and roof structures to carry roof lateral loads that were previously taken by the ceiling joists. Reinforcing an existing structure to allow removal of ceiling joists to create a cathedral ceiling can be complicated and expensive.

Cable stayed structures offer architects and engineers an effective means to replace existing ceiling joists. Steel cables provide excellent tensile strength. A single small diameter cable can effectively replace many ceiling joists. Cables can be used to create long open spans within an existing structure, and, with careful planning and design, arranged in a myriad of patterns.

Design of a cable stayed cathedral ceiling involves careful coordination between the Architect, Engineer and Contractor. The cable stayed structure must be designed to interface with the existing structure and involves fabrication and installation of new components that must attach to the existing building. Components must be carefully detailed to ensure the structural integrity of the existing structure while simplifying construction and installation.

Prior to installation of the cable stayed system, a mockup of the new cable stayed system can be built from wood, rope and PVC. A system mockup will help eliminate potential costly problems and is well worth the time and expense. Lengths of rope can be cut to size, accounting for all fasteners and end connections can be used to simulate the wire cables. PVC pipe provides a good representation of steel pipe and connecting hardware can be replicated by shapes cut from plywood. The mockup should be built to scale with design dimensions used to ensure everything will fit together when it arrives in the field.

1 INTRODUCTION

Architects and Engineers are often called upon to modernize existing buildings. Updating an existing structure is often challenging work. However, by working together, the Architect and Engineer can come up with creative and cost effective designs that incorporate innovative materials to achieve the Architect's vision of the updated structure while retaining the structural integrity of the building. Installing a cathedral ceiling into an existing building presents many design and construction challenges that can be solved with the use of cable stayed structures. Cathedral ceilings are a common feature to many new homes in the United States. A cathedral ceiling provides a large, light airy space that people often want replicated in older houses.

One of the primary differences between a cathedral ceiling and a conventional ceiling is the elimination of ceiling joists. However, the building's structural integrity is compromised if ceiling joists are simply removed to create a cathedral ceiling. Normally, existing gable end walls must be reinforced and large beams installed along bearing walls to transfer lateral loads from the roof rafters to the newly reinforced, gable end walls. New cable stayed structures allow ceiling joist removal without requiring extensive additional reinforcement to the existing structure. Incorporating structural steel cables into the cathedral ceiling design provides a cost effective method to modernize an older residence with a new cathedral ceiling.

2 DESIGN CONSIDERATIONS

Cable stayed structures offer architects and engineers an effective means to replace existing ceiling joists. Steel cables provide excellent tensile strength and a single, small diameter cable can effectively replace many ceiling joists. Cables can be used to create long open spans within an existing structure, and, with careful planning and design, arranged in a myriad of patterns.

A pitched roof generates lateral loads where the roof rafter lands on the building side wall. In typical residential construction, each set of roof rafters is fastened to a ceiling joist which forms the bottom chord of a triangle. In order to form a cathedral ceiling, the bottom chord of the triangle is removed. Without any ceiling joists, roof rafters want to kick out the building side walls as depicted in Figure 1. In order to resist roof rafter generated lateral loads from the cathedral ceiling, the building is typically reinforced with shear walls and large beams that transfer roof rafter lateral loads to new shear walls. Oftentimes, these shear walls end up on the gable end walls of the building resulting in long spans that require large beams along the top of the side walls. However, small diameter cables can be used to resist roof rafter generated lateral loads. Cables act much like the ceiling joists that they replace and eliminate the need to structurally reinforce the existing structure. Each cable is capable of replacing numerous ceiling joists and presents a minimal profile that effectively converts a conventionally framed ceiling into a large, open cathedral ceiling.

Design considerations must include verifying that cables are not put in compression when the building is subjected to lateral load conditions. One constant structural load is the weight of the roof which acts to put tension on either the original wood ceiling joists or the steel cables used to replace the ceiling joists. Lateral wind loads and seismic loads can act to reduce cable tension and can even put the cables in compression if not properly accounted for. Compressive cable loads generated by lateral loads must be compared to tensile loads generated by the weight of the roof to verify that the cables will always remain in tension. This relationship is also shown in the Figure 1. In order to ensure the cables never go into compression, the weight of the roof must sufficiently preload the cables to ensure the cables are always in tension for all building load conditions.

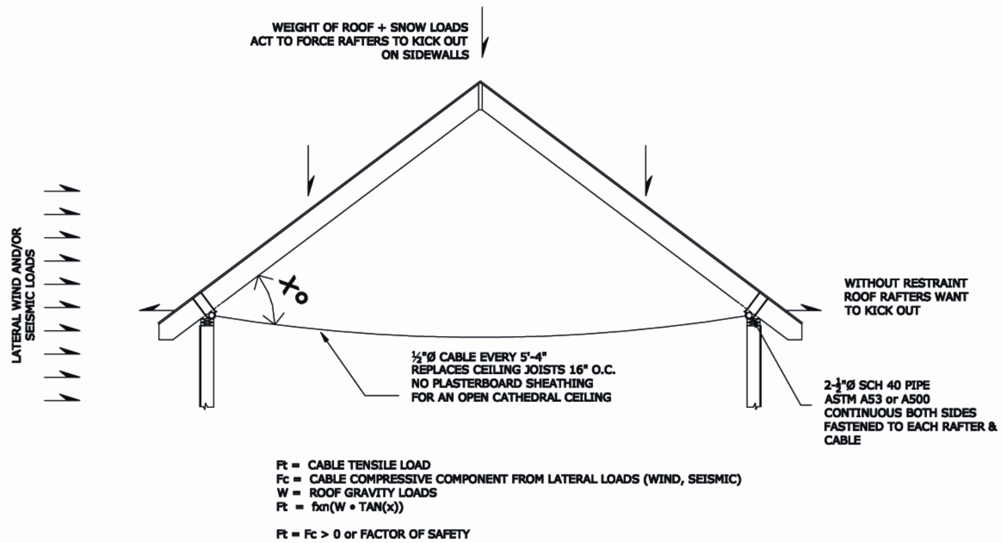

Figure 1 Roof Loads and Cable Forces

In order to provide an open, airy cathedral ceiling, the number of cables should be kept to a minimum. The number of cables that will be used is determined by calculating the load on each set of rafters and then figuring how many rafters a single cable can replace. For example, if each set of rafters imparts 2,500 lbs of lateral load into the side walls and each cable can carry 10,000 lbs of tensile load, a single cable can replace four ceiling joists. Note that these calculations are somewhat simplified for this presentation and should include a factor of safety.

In order to transfer tensile loads from the roof to the cables, the cables must be attached to the rafters. However, each cable replaces multiple ceiling joists, which means multiple rafter loads must be transferred to a single cable. An effective, low profile method to transfer muliple rafter loads to a single cable is by using a standard size structural steel pipe running perpendicular to the rafters for the length of the new cathedral ceiling. The pipe transfers multiple rafter loads to each cable and is fastened to every rafter with angle brackets and U-bolts. Each cable is fastened to a steel plate cable standoff welded to the pipe located periodically along the length of the pipe. Each steel plate cable standoff must be centrally located between rafters that the cable is used to support.

3 FABRICATION AND INSTALLATION

Design of a cable stayed cathedral ceiling involves careful coordination between the Architect, Engineer and Contractor. The cable stayed structure must be designed to interface with the existing structure and involves fabrication and installation of new components that must attach to the existing building. Components must be carefully detailed to protect the structural integrity of the existing structure while simplifying construction and installation.

Components used to construct the cable stayed ceiling design incorporate materials not normally used in residential building construction although all materials are readily available through retail supply houses. For example, cables can be procured from a marine supply house. Even though these cables are normally used to rig sailboats, the cable load capacities are well documented and can be confirmed with structural calculations. Marine cables can be easily ordered to include standard marine end fittings and turnbuckles. The end fitting requirements are then used to design attachment points on the connecting hardware. The cables and fittings are swaged together and proof tested by the supplier to ensure their structural capacity prior to delivery.

Each of the components needed to attach the roof rafters to the cables can be fabricated by a typical steel fabrication shop. For example, angle brackets can be cut from standard structural angle stock and predrilled to attach to both the pipe and roof rafters. The angle brackets are fastened to the pipe with standard size structural U-bolts sized to wrap around the pipe. The legs of the U-bolts pass through predrilled holes in the angle brackets. The other leg of the angle brackets are bolted to the roof rafters again through the use of predrilled holes in the other leg of the angle bracket. This arrangement is repeated for each set of rafters. For every cable, a steel plate standoff is welded to the pipe. The standoff is drilled with a hole sized to fit the cable end fitting which is pinned to the standoff. Each cable is fitted with a turnbuckle that is used to adjust cable tension. A photograph showing the installed brackets, pipe and cables on one side of the roof is shown in Figure 2.

Prior to fabrication and installation of the cable stayed system, a mockup of the new cable stayed system can be built from wood, rope and PVC pipe. A system mockup helps eliminate potential costly field problems and is typically well worth the time and expense. Lengths of rope can be used to simulate the cables. The rope is cut to length, accounting for all fasteners and end connections. PVC pipe provides a good representation of the steel pipe and connecting hardware can be replicated by shapes cut from plywood. The mockup should be built to scale with design dimensions used to ensure everything will fit together when it arrives in the field. The mockup can be also used to verify how the cable installation will finally look when installed.

Final assembly in the field will be relatively simple if the design team and construction crew have properly prepared for the installation. The mockup previously described will have prepared the construction crew for what to expect when the fabricated components arrive on site. The design should include accounting for variations in the fabricated piece parts and anomalies in the existing building. Clearance requirements for the cable fittings and angle brackets along with tool clearances for assembling should have been carefully calculated and confirmed with the mockup described above to ensure a problem free installation. Careful design will help ensure that fabricated cables, angle brackets and pipes fit right into the existing space. See Figure 2 for a photograph of an actual installation.

Figure 2 Cable Stayed Cathedral Ceiling Installation in Progress – Typical Both Sides

4 SUMMARY

Collaboration between the Architect and Engineer can result in use of innovative design elements for dramatic effect in residential and commercial building construction. Structural elements not usually incorporated in convential building design can be used to achieve aesthetically pleasing structures that delight owners, Architects and Engineers alike. Steel cables normally used to construct sailboat rigging can replace convential framing and transform an ordinary room into a large open space with a cathedral ceiling. Success in such projects can depend on efforts of the Architect and Engineer to locate cost effective sources for the separate building elements. Use of new materials and methods often requires additional construction support from the Architect and Engineer to ensure all contractors understand how the new system is to function in operation. Support can include working with the construction crew to create mockups of the actual construction to ensure a structurally sound and visually appealing design results.