ADVANCING STEEL STRUCTURES WITH COMPOSITE FLOOR SYSTEMS

Composite floor systems provide structural framing approaches that bring efficiency and versatility to building design.

4 LEARNING OBJECTIVES

After reading this article, you should be able to:

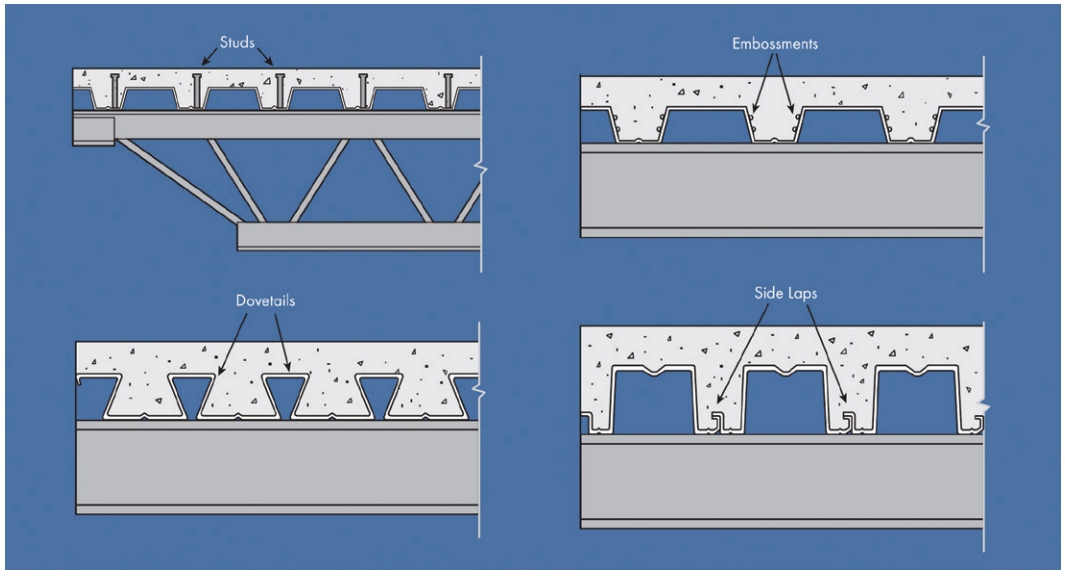
- **DESCRIBE the use of composite floor systems to reduce structural framing costs and simplify construction sequencing to create a unified load-bearing system.**
- **DISCUSS how long-span deck systems achieve open structures to maximize clear spans with effective framing weight reductions.**
- **LIST the applications and relative benefits of composite joist and deck that can be used as floor systems.**
- **DESCRIBE how composite floor systems have been employed in various building types and applications, including new construction, adaptive reuse, multi-story and large-venues.**

WHY COMPOSITE FLOORS?

For a typical building project, the construction and design team face a range of choices in steel-based floor systems. One of the team's biggest hurdles to clear is selecting the most appropriate, functional, and cost-effective floor system. The structure should benefit project delivery, offer design efficiencies, and withstand the test of time.

This course considers the benefits and diversity of composite floor systems which, in recent years, have been gaining market share due to design improvements and creative applications. In this course, both composite joists and long-span composite deck systems will be addressed, with a range of steel-based floor systems presented in general terms. The relative advantages of each system is identified for comparison against the requirements of common commercial project types. The overview offers insights for building planning decisions, and identifying basic technical details that project leaders should understand about types of composite, long-span, and shallow-floor solutions.

The Increased use of composite floor systems can be attributed to four key qualities, according to Angelo Nieves, P.E., an engineer



There are many variations of composite deck, each having features designed to bond with the poured concrete slab to develop a composite floor system. Once the concrete cures, the resulting composite floor system provides superior strength and stiffness.

with New Millennium Building Systems. The first quality is project economy. Composite steel-joist floor systems developed to support a floor slab tend to be lighter, shallower, and less expensive than assemblies built with non-composite joists. The second quality is maximizing space availability. Long-span composite floor systems reduce the quantity of supporting members needed to create wide spans and allow for greater floor-to-floor heights. The third quality is using deck as an exposed and finished ceiling system. Deep rib, deep rib cellular, and dovetail composite deck used in composite floor systems can be left exposed, creating an aesthetically pleasing ribbed, smooth panel, or lineal plank ceiling appearance. The fourth quality is improved structural engineering and construction sequencing. These approaches can simplify project design and delivery by creating a unified load-bearing system. Ultimately, this streamlines logistical planning for project work schedules. Additional considerations which relate to the supply network for composite floor systems should also receive attention. With composite floor systems, building teams can take advantage of value-added benefits provided by the material supplier, such as integrated steel detailing, project engineering support, and vibration analysis for sensitive building types.

Applications of composite floor systems have expanded over recent years in both the U.S. and overseas markets in the areas of adaptive reuse, multiple-story, and large venue facilities. Midrise and high-rise residential buildings, in particular, have benefited from the long spans and higher ceilings afforded by composite floor structures. Universities and schools have used composite floor systems for both academic and residential facilities. Elements such as radiant heating have even been introduced to deep rib composite floor systems. The projects covered in this course include: hospital additions with precise vibration control needs, open-span concourses in airports, vertical shopping malls, and economical parking garages.

To tap into these opportunities, today's building teams should review composite floor options made possible by three structural categories covered in this course:

- Composite steel joist and deck systems
- Long-span composite floor systems
- Composite steel deck profiles which include: dovetail, deep rib, cellular, and the acoustical versions of these types of composite systems

COMPOSITE JOIST AND DECK: OPTIONS FOR APPLICATIONS

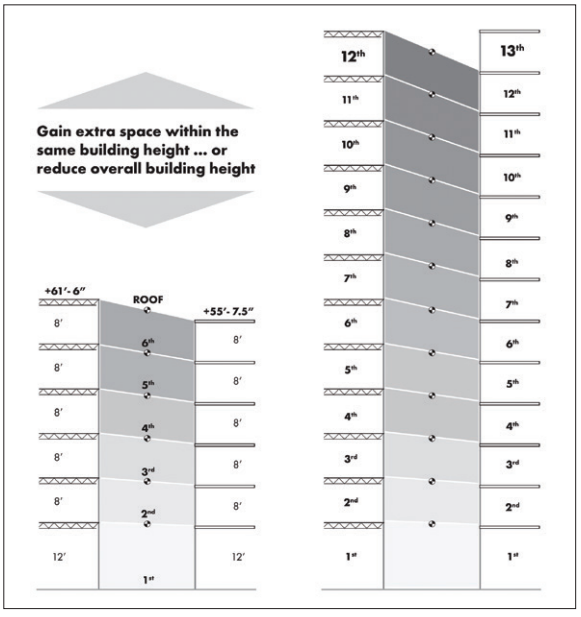
To begin working with composite floor systems, building teams need to consider the applications of composite steel joists, as well as long-span deck systems.

Composite steel joists offer advantages over standard steel joists which are defined by the Steel Joist Institute (SJI). Composite joists are manufactured specifically to support floors and roofs with a structural composite deck. Unlike standard joists, composite systems have shear studs attached through the composite deck to the top chord of the joist. After the concrete cures, the composite joist and deck achieve full design load capacity. Engineers calculate the design loading of the joists by including the joist self-weight plus the weight of the wet concrete, equipment, personnel and other loading variables anticipated throughout the slab pour and curing. Standard non-composite joists, conversely, are built for full design loads since they have no shear studs to exploit the slab's added strength. An additional benefit of composite joists is that they can be lighter structural elements than a wide flange beam.

Composite floor deck with their efficient shear studs locked into the relatively lightweight slab are time-tested and widely effective, according to experts including W. Samuel Easterling from the American Institute of Steel Construction (AISC) publication Engineering Journal in 1993 (Vol. 30, pp. 44-55). “Composite beam or joist and deck systems typically provide the most efficient design alternative in steel frame construction, and indeed it is one of these systems that make steel an economically attractive alternative to concrete-framed structures,” writes Easterling and his co-authors.

According to engineers and fabricators familiar with both composite and standard approaches, composite joist and deck systems can achieve substantial weight savings and cost reductions. For example, standard joists are often spaced 2 feet on center in conventional designs, while a composite joist system may be spaced 4 to 5 feet on center, or greater. Spacing joists farther apart can reduce steel material cost, manufacturing and detailing work, transportation needs, and erection time by steelworkers on the jobsite. "For optimal cost savings," says engineer Angelo Nieves, "the building team’s objective is to design floor structures with composite joists spaced further apart than in non-composite joist floor structures, achieving the maximum practical joist-to-joist dimension."

Composite long-span deck can provide a finished ceiling and a finish-ready floor requiring minimal added treatment for acoustical isolation. Deep rib composite steel decks can span up to 36 feet and dovetail composite deck can span up to 28 feet between support members. These systems can also be made acoustical, consolidating multiple building components, phases, and trades. Acoustical composite long-span deck comes in two varieties, deep rib cellular composite acoustical and dovetail composite acoustical. A perforated liner panel is added to a deep-rib composite deck, or perforation is added to the plank portion of a dovetail composite deck with a metal cap, to protect the insulation within the plank of the dovetail deck. The combined properties of span and acoustics can positively impact the project schedule and contribute to quicker building erection. By eliminating secondary ceiling systems or acoustical treatments, the design team can reduce the project costs for both material and labor.

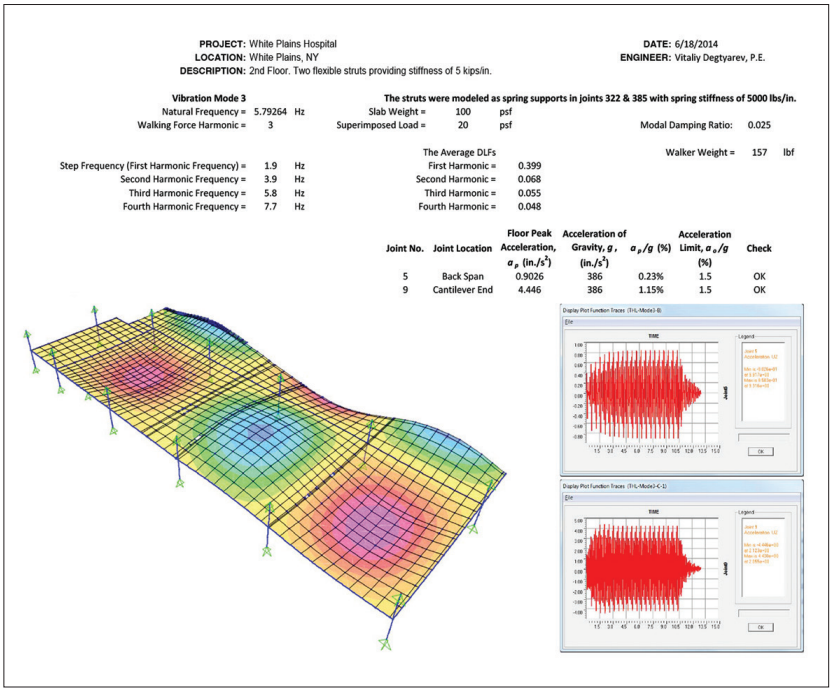


Long-span composite deck can contribute to an overall reduction of project height which can save money and allow for an additional floor at the same total building height.

Another valuable attribute of long-span composite deck is the reduction of floor-to-floor heights. Consider a hypothetical six-story building with a 12-foot-tall first floor and with 8-foot, floor-to-ceiling, subsequent floors above that. With standard steel joist construction, the anticipated height will be about 61 feet, 6 inches. Using composite floor systems such as long-span floors, the total height would be 55 feet, 8 inches. Multiply the height advantage by a few more floors, and the owner could add another floor. This translates to more floor area and more revenue-generating value at the same height as comparable buildings.

With long-span composite floors, other design benefits accrue. Namely, fewer columns interrupting floor plates, and added space for occupancy needs and building systems between joists and vertical structural

Headed shear studs welded on-site to the top chords of the joists provide added structure for the concrete to bond with. When the concrete cures, the steel joists, decking, and concrete become integrated components. The resulting composite structural system is considerably stronger than either component alone.



Vibration control in laboratory and healthcare facilities as well as the strength needed to support heavy equipment is possible with composite floor systems such as in this hospital addition.

supports. For many projects, integration of mechanical, electrical, and plumbing (MEP) systems through joist members and deck components can enhance space availability and streamline interior assemblies. Radiant heat can be added to deep-rib composite slabs and ductwork and conduit can be run though joist openings.

CASE STUDY: *A Hospital Limits Vibration*

Vibration control is critical, especially in laboratories and healthcare facilities. These buildings may have sensitive equipment or needs for damping of noise and reverberation to benefit patients. Composite systems can benefit these buildings thanks to the manufacturer's ability to model potential vibration and offer ways to mitigate the effects of live-load movement.

A six-story oncology care facility in White Plains, New York, employs long-span composite deck to support ceiling-mounted equipment in operating rooms. The composite systems also limit vibration for optimal patient outcomes by reducing slab deflection typically caused by concrete shrinkage and creep, and by adding top reinforcing bars in some areas. (These techniques are outlined in AISC Design Guide 11.)

Each floor structure was customized to the anticipated uses and vibration control needs, reflecting their different programs. For example, operating room floors employ a system of steel girders and filler beams topped by a 3-inch-deep composite floor deck topped with 5.25 inches of concrete.

For office and patient room floors, a long-span floor system combines a 7.5-inch composite joist deck with 5.375 inches of concrete, set atop steel beams spanning more than 25 feet. By eliminating filler beams, the floor-to-floor height could be reduced while still accommodating all MEP equipment and ducts.

GOING LONG: LONG-SPAN DECK SYSTEMS

As the hospital example shows, when developing composite floor systems for a range of commercial and institutional projects, innovative building teams have effectively employed long-span deck systems in diverse ways. These systems optimize span length and floor-to-ceiling depth to create efficient multi-story applications, large-venue interiors, transportation hubs, and sports facilities. Deck vibration analyses can model and predict how the systems will perform under occupant loading and expected activities within the facility.

In addition to hospitals, long-span composite deck systems can be used in a wide range of building types such as commercial, MSR (multi-story residential), and institutional projects. Multi-story construction is one of the fasting growing markets for this system. Adaptive reuse projects have utilized this system as well.

A long-span composite floor system comprises three elements: long-span metal deck, steel reinforcement, and a concrete slab. The basis for these longer spans initially lies within the long-span deck profiles, either a deep rib composite deck or dovetail composite deck. The profile heights of dovetail composite deck are most commonly 2 inches and 3.5 inches, and the profile heights of deep rib composite deck are 4.5, 6, and 7.5 inches. A 3.5-inch dovetail composite deck can potentially reach a clear span of up to 28 feet and a 7.5-inch deep rib composite deck can potentially reach up to a 36-foot clear floor span. For reference, standard composite floor deck (CFD) comes in three common profile heights 1.5, 2, and 3.5 inch and its maximum clear span is typically 14 feet.

Deep rib composite deck can utilize the " panelized delivery method" within a project site. The deep rib composite deck is placed within a structural steel frame on the ground and then is lifted into position within the building. This process can aide in the speed of erection

A long-span dovetail composite floor system created thin slab floors that span unsupported up to 28 feet wall-to-wall for the Elan Heights Luxury Apartments. Living spaces were maximized by open spans and space-efficient floor-to-ceiling heights. Thin floor slabs reduced overall building height and related building material costs.

for buildings 6 to 7 stories or taller and also provides for a safer construction site with fewer laborers working off the ground.

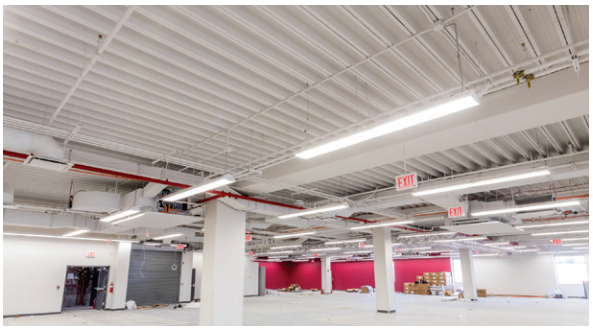
This delivery method can help reduce erection time for the overall structural building frame, according to engineers with the contractor Flintco. In some instances, building teams have achieved a construction rate of 6,000 square feet per day when utilizing the panelized delivery method and installing panel sections of 300 square feet and greater.

The span-to-depth ratios for deep-rib composite deck systems are equal to those of traditional cast-in-place concrete and hollow-core plank. The deep flutes of the deep-rib composite deck can create a dramatic aesthetic when left exposed while improving space utilization and MEP system integration. Some building projects have integrated long-span systems with cast-in-place communications and electrical boxes which have helped create a seamless and more integrated building infrastructure.

In contrast to a cast-in-place slab system, a long-span composite deck system can reduce overall floor weight and allow for smaller framing members and thus contribute to cost savings, according to the authors of a white paper written by Shanghai's Tongji Architectural Design and their real estate developer on super-tall multifamily towers. In addition, the white paper authors concluded that because the steel shear members are embedded in the slab height, towers can benefit from the reduced height of each story. Another benefit of long-span composite floor systems is its integration with all weight-bearing beam and framing options to provide up to 40% less dead weight than cast-in-place concrete systems, according to engineer Nieves.

Life-safety experts note that long-span systems are intrinsically fire resistant up to 4.0 hours, depending on the floor assembly design, without the addition of fire-resistive spray or gypsum protection. The ability to acoustically isolate floors is desirable for many project types, including

For high-rise applications, the panelized delivery method lowers costs by lowering much of the deck construction process to the ground level. At-grade panel assembly speeds erection and improves safety onsite.



The long-Span composite system used in this revitalized, vertical shopping mall combines the structural advantages of a flat-plate slab with the time and cost-saving advantages of a permanent form slab. Accommodating clear spans up to 36-feet, the system is ideal for retail structures such as this one in the heart of Harlem.

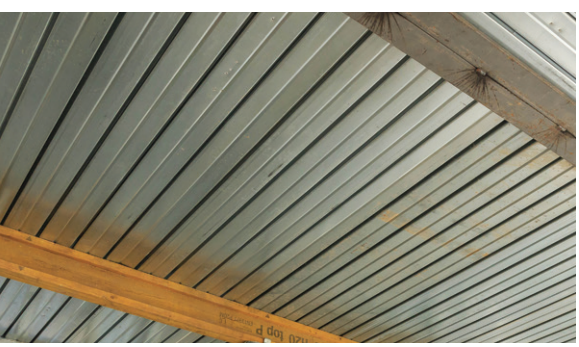
hospitality and residential. Composite floor systems effectively attenuate airborne sound and transmitted impacts before the addition of complementary acoustical treatment. Comparing manufacturer data with sound ratings required by the International Building Code (IBC), composite floor systems handily meet the needed levels for Sound Transmission Class (STC) and for impact sound transmission, given as IIC. According to engineers at Bayside, a Bellingham, WA-based subcontractor, "The lowest IIC rated floor-ceiling assemblies come in at around 25 and the highest-rated systems can come in at 85 and up."

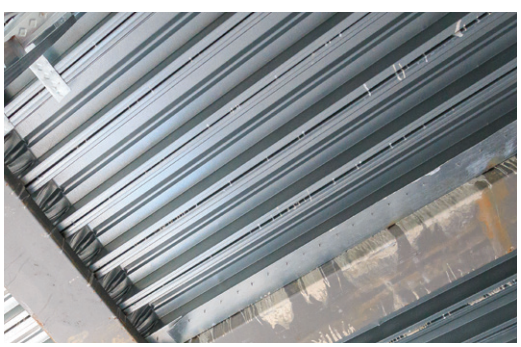
For these and other reasons, long-span composite assemblies also work well for building projects designed to achieve U.S. Green Building Council LEED certifications. Comparing the cost contribution and savings of the structural framing and the long-span composite floor systems shows advantages in lower total materials used, improved pre- and post-project waste, reduced transportation fuel use, and longer-term Life-Cycle Assessment (LCA) benefits. These additional benefits include improved energy efficiency through more open building spaces with increased daylighting and airflow.

Dovetail composite deck profiles: These composite floor systems utilize the inherent strength and aesthetic appeal of the dovetail shape. Many designers specify dovetail deck due to its lineal plank aesthetic when exposed as a finished ceiling system.

CASE STUDY: *Clearing the Decks for a Vertical Mall*

This revitalized vertical shopping mall on a prominent intersection in uptown Manhattan delivered six stories of retailing above ground, plus an active cellar level for such brands as Whole Foods, TD Bank, and American Eagle. The magnetic, 202,000-square-foot commercial-retail venture, developed by Wharton Properties and designed by Gambino + LaPorta Architecture, employs a





Composite deck types: Standard composite deck systems are manufactured with embossments in their vertical ribs that bond with the concrete slab to develop a composite floor system. Composite decks act as a form during the concrete pour. When the concrete cures, the resulting composite floor system provides greater strength and stiffness as a hybrid structure.

long-span composite floor system to combine the structural advantages of a flat-plate slab with the time- and cost-saving advantages of a permanent-form slab. Accommodating clear spans up to 36-feet, the composite long spans make room for double-height escalators and wide open retailer spaces.

According to the construction team, the long-span composite system contributes to making 100 West 125th Street in Harlem an unmatched retail experience in the area. The large spans allowed the project to come online sooner with significant cost savings over other structural floor approaches.

SELECTING FLOOR DECK TYPES

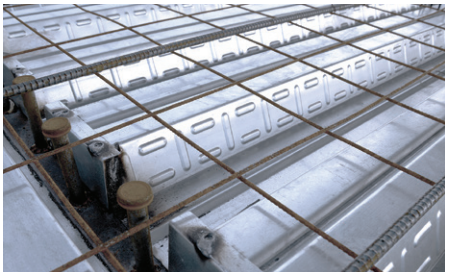
As shown by the cancer hospital and the vertical mall case studies, composite floor systems are customizable, versatile, and adaptable in application. Building teams succeed not merely by choosing to use these floor systems, but also by tailoring their features to suit specific objectives and opportunities. Critical to the system specification is the choice and detailing of the floor deck.

To illustrate, consider the Sky Train Station built for the Sky Harbor Airport in Phoenix. The aircraft-inspired, sleek, curved, ceiling plane extends column-free across the full width and length of the modern transit stop. Designed by global architecture firm HOK, the facilities totaling 200,000 square feet achieved LEED Gold, saving 30% on energy costs while serving 2.5 million riders per year.

Deep rib decks: These decks are characterized by larger profile depths of 4.5, 6, and 7.5 inches and high-performance spans of well over 30 feet. They can provide a deep fluted look for dramatic underside aesthetics, while their cellular versions also conceal integrated MEP system components.

Cellular deep rib deck: Supporting the Sky Train station are long spans of deep-rib cellular acoustical deck, which help to create a comfortable, enjoyable riding experience. The architectural deck was prefinished with a protective coating to help withstand Arizona's desert sun, and the exposed system requires minimal maintenance even though the station is a heavy-use application.

Dovetail composite deck profiles: These composite floor systems utilize the inherent strength and aesthetic appeal of the dovetail shape.



The aircraft-inspired, column-free design of the Sky Train station of the Phoenix Sky Harbor Airport is supported by long spans of cellular composite deck. The deck was pre-finished with a protective coating to help withstand the brutal Arizona sun. The durable materials will require minimal maintenance even though they are in a heavy use application.

Many designers specify dovetail deck due to its lineal plank aesthetic when exposed as a finished ceiling system.

The building team for Clemson University's Watt Innovation Center employed a deep rib-deck composite deck to achieve wide-open student collaboration zones and a simplified, modern appeal with its exposed, primed, and sealed metal surfaces. "Located on a long, narrow site adjacent to a vibrant and active campus quadrangle, the facility engages passersby and invites students to take ideas from concept to marketplace," as the Perkins+Will website describes the 70,000-square-foot, LEED Silver-certified facility constructed by Turner.

COMPOSITE FLOORS, COMPOUND BENEFITS: APPLICATIONS AND SOLUTIONS

Capturing the opportunities and relative advantages of composite floor systems are a series of recent building projects ranging from historic lofts adapted as luxury homes, to city-making large venues for sports and music. The innovative highlights of these projects help demonstrate how and why composite floor structures are applied.

The ultra-modern, highly versatile building on the Clemson University campus is designed as two triangles nestled beside one another and forming entry points. The clear spans of the airy, open collaborative center are supported by exposed, primed, and painted composite deck.

For the Huntsville, Texas-based Sam Houston State University's Piney Woods Residence Hall, the composite floor system is utilized on a multi-story residential design approach. Architects at Stantec, in association with Treanor Architects, designed the building with dovetail composite deck spanning from exterior light gauge steel-framed walls to its corridor supports. This newest residence hall, in the South Residential Complex, houses 684 students and provides a large ground-floor community space with an open, wide-span ceiling. "This creates opportunities for all Sam Houston students to congregate, study, and collaborate," according to a post on the Stantec website. The dovetail composite deck provides exceptional acoustical separations, a low-floor depth assembly, and its wide span reduces costs by eliminating load bearing walls between residences.

The unique capabilities of dovetail composite deck used in Sam Houston University's Piney Woods Residence Hall allow spans from the exterior walls to the corridor supports, reducing costs by eliminating load bearing walls between residences.

Another multi-story residential project was developed by architect John Cetra, FAIA, of CetraRuddy with a project team led by the developer MetroLoft for a high-end condominium building adapted from a large historic building in New York City's trendy Tribeca neighborhood. The 54-unit project, 443 Greenwich, has attracted A-list buyers from Hollywood and the music industry. It not only demonstrates the effectiveness of long-span composite deck for luxury homes, but also for historic buildings where the existing structure is being gutted and replaced in an adaptive reuse.

CetraRuddy selected a long-span composite floor system allowing for long spans and a relatively slender, lightweight floor assembly with excellent acoustical performance and the ability to integrate MEP tubing for radiant floor heat. The primary goal was to preserve the original structure while employing space-optimized design to boost unit count, spaciousness, and ceiling heights. Integrating a long-span composite floor allowed the retention of original exposed wood columns and beams, while opening the design space to a degree not achievable using deeper, conventional floor structures.

This system has also shown adaptability for expanding structures and interiors for more recent urban landmarks such as the 102-year-old

A long-span composite floor system enabled the preservation of the original structure of this historic building. The integration of the thin-slab floor allowed the retention of the original exposed wood columns and beams, while opening the design space to a degree not achievable using deeper, conventional floor structures.

Texaco Oil Building in Houston. Reimagining the historic landmark as luxury apartments required a full renovation and adding a 28-story tower atop its adjacent parking garage, to offer 500 parking spaces for the 286 residences.

Developer Provident Realty Advisors earned historic tax credits by preserving the Renaissance Revival exterior, with Beaux-Arts accents, by firm Warren & Wetmore, known for designing Grand Central Terminal in New York City, where the firm was based. The architect, HBG of Memphis and San Diego, also worked to keep the project economical and affordable relative to other market-rate offerings.

Presbyterian Hospital in Charlotte, NC, employed deep-rib composite floor systems for a lightweight and cost-effective vertical expansion that would allow for clear spans of 21 feet without columns. Integration of key MEP and IT systems was also essential. “The F-Wing is a four-story vertical expansion for the main campus that includes 90 new in-patient beds, a cardiac triage suite with 20 exam rooms, isolation rooms for an intensive-care nursery, education classrooms, and new suites for hospital security and information technology,” according to the website of McCulloch England Associates Architects.

Controlling added weight became a critical project driver, as the building team constructed the new spaces directly above a fully operational cancer center. The low profile of the new floor system and the ability to precisely match the existing wing’s floor heights demonstrate yet another benefit of composite floor assemblies: An original expansion plan called for ramping between old and new floors, which was unnecessary in the final design.

For the city of Tampa’s Seaport Channelside Parking Garage, the building team achieved even larger clear spans of 28 feet on a concrete frame with pass-through integration of MEP systems through the composite joists and dovetail-shaped floor decks, according to engineers at the Tampa electrical design-build firm Colwill Engineering. Utilizing building information modeling (BIM) to integrate electrical systems, the floor assemblies had premade cuts and channels to accommodate fully LED lighting systems – a first of its kind, according to engineers at Colwill.

Bright lighting adds to the parking facility’s white concrete appearance creating an inviting and safe aspect to the Port of Tampa. It is also a memorable building form, as the four-story garage has a cantilevered projection over the sidewalk below. The composite floor systems

The conversion of the historic Texaco Oil Building into high-end rental units brought new life to a long-deserted site in the middle of Houston. A deep deck composite system blended the speed and versatility of steel with the performance and durability of concrete.

help ensure lightweight floor assemblies that are among the lowest possible floor-to-floor heights for a standard garage. This reduces structural system loading and eases the design of the overhangs. Most importantly, the composite floor systems improved scheduling and reduced costs — a critical component of project feasibility.

Another project type that often creates major challenges for building teams is the large-venue interior, used for athletic and entertainment events. These specialty platforms often include dramatic shapes and openings that lend themselves to steel and composite solutions.

One powerful example is the acclaimed 2.1 million-square-foot Music City Center in Nashville designed by architecture firm tvsdesign with Tuck-Hinton Architects and Moody-Nolan. Built by a team led by Clark Construction, the structure is recognizable by its curved barrel joists, reminiscent of a guitar shape. The facility uses

Lightweight structural design was important on the Presbyterian Hospital project because the expansion was being constructed on top of an operational cancer center. Low-profile floor plate and matched floor heights eliminated ramping between the new and existing wings.

steel joists and deck with vertical structural steel transitions into a pitched and sloped roof. The detailing of the system was critical to achieving exact joist angles, helping the project earn tens of thousands of dollars in structural cost savings and achieve LEED Gold.

According to engineers at Clark Construction, budget cuts during the project's design phase made economical solutions more critical than ever. About $50 million, or 10% of the total cost, was trimmed from the construction estimates as required by financing requirements. Yet, the building team found many innovative and economical ways to complete the promised design. As the president and CEO of Music City Center, Charles Starks, has said, "Some people would have looked at this project and thought, 'How in the world are we going to make this happen?' Instead, this team looked at every potential obstacle as an opportunity and asked, 'How do we capitalize on that?'"

CONCLUSION: COMPOSITE SKETCH

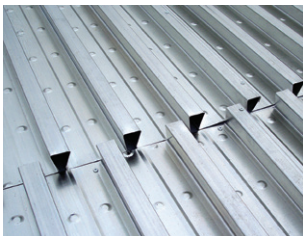
While Nashville's amazing Music City Center employs curved standard joists and a steel deck system above for its big signature look, the project is a reminder that in many situations building teams can employ both standard joists and composite floor systems now used in so many building types.

To do this, building teams need to consider composite floor systems in a project's early design phase. The product range includes composite steel joist systems and composite steel deck systems, as well as long-span composite floor systems. There is a variety of composite steel deck profiles including: dovetail, deep rib, standard composite, deep rib cellular, standard composite cellular deck and the acoustical versions of these composite deck systems.

The reasons for using these systems are manifold, but building teams conclude that the decision-making often boils down to one or more of these four reasons:

- Achieving weight savings and cost reductions
- Simplifying erection and construction sequencing
- Reducing floor-to-floor heights
- Improving space utilization, MEP system integration, and other design benefits

These advantages can provide the justification for a building team to utilize long-span composite deck and composite joists on a variety of project types.



The composite deck utilized in this parking garage harnessed the inherent strength and aesthetic appeal of the dovetail shape to achieve concrete beam integration, reduced overall story height, and streamlined MEP pass-through capabilities that sped erection and reduced costs.

Nashville's Music City Center has many distinctive architectural features that mimic the rolling hills of the Tennessee landscape and the flowing shape of an acoustic guitar. The grand entryway, fabricated using six tons of special profile steel arched barrel joists covered in steel deck, imparts a horizontal thrust to the supporting structure.