Precast Prestressed Double-Tee Concrete Parking Garages

By Jeffrey M. Reder, P.E.

Parking garages frequently use long span construction, with a typical framing system of beams or joists spanning approximately 60 feet across parking spaces on each side of a center driving aisle. If there is no other building use constructed above the garage that requires closer column bays, this is the preferred garage layout because most drivers have a difficult time maneuvering around and parking next to interior columns. Also, patrons feel more secure in long span garages because the garage is open and better lit.

A number of framing systems are common for long span garages. These include: 1) cast-in-place postensioned concrete beams and slabs, 2) steel beams (sometimes castellated) with a slab, and 3) precast prestressed concrete double-tee systems. Each system has distinct advantages. Every potential project should be evaluated relative to its own situation and conditions to determine the best system for a given project.

Double-Tee Garage Construction

The double-tees usually have 8- to 12-foot wide concrete flanges with two tapered stems or ribs extending downward approximately 32 inches. In the past, the flange was only about 2 inches thick, and a 2- to 3-inch thick composite concrete topping was placed in the field over the entire garage. Now, many garages use double-tees with a flange thickness of 4- to 5- inches. These are called "pre-topped" which is just a thicker flange and not a topping at all. With "pre-topped" flanges, a waterproof joint along the edges of every double-tee must be installed, and a larger crane is needed to erect the precast. The main advantages of "pre-topped" units are faster construction and economy. Double-tees typically bear on precast bearing/shear walls or precast concrete beams. These beams are an inverted tee-shape when used on the interior of the garage, and L-shaped on the exterior. Precast walls on both the exterior and interior typically have holes cast in them to allow light through.

Angle welded to top of spandrel beam and column transfers tension from negative moment at joint. (Ring was used to suspend angle when dipped in galvanizing tank).

Exterior shear wall panels. "Columns" in panels are at six feet on center and projecting brackets are designed to support double-tee stems of future addition.

Building adjacent to parking garage.

Lateral Loads

The lateral system chosen for a precast concrete parking structure can greatly influence the design and detailing of the remainder of the structure. In a typical open precast concrete parking structure, the seismic loads control the design over the wind loads. Due to the high seismic mass of the structure, the response modification coefficient (R) can greatly influence the seismic design and detailing for the lateral system.

The lateral force resisting system for precast structures is typically Ordinary Reinforced Concrete Moment Frames (R=3.0) or Ordinary Reinforced Precast Shear Walls (R=5). This is not to say other lateral force resisting systems cannot be used, but that this article will focus on these two systems. Obviously, other considerations can sometimes drive the decision as to which lateral force resisting system to use. However, using a higher R-value can greatly reduce the design lateral seismic force in the system. Using shear walls will reduce the overall design force by 40%, as the seismic design coefficient (C_s) is inversely proportional to the response modification factor.

How does this affect the design and detailing of the remainder of the building? For starters, depending on the total mass of the building and the seismic design category, the diaphragm shear connectors (double-tee flange to flange) will be reduced for a system with a lower "R" value. Not only does this lower the material cost of the building, but also reduces the erection time as there are less welded connections to consider. Less welded connections may also help alleviate shrinkage cracking and/or cracking due to the heat of welds around the flange connectors. As the number of connections increases, the ability of the structure to expand and contract decreases, thereby forcing cracks in other less desirable locations. The cracking can also create serviceability issues related to water infiltration and corrosion due to salt or other substances used for deicing.

One item to consider with moment frames is the complexity of the connection in comparison to those used in a shear wall system. The amount of welding required to develop the moment connections can be much greater. This potentially adds time and expense to a project. The moment connections can also create difficulty in precasting – not only the spandrel beams but the columns as well. Typically the moment connections consist of embedded plates with either headed studs or bent reinforcing bars. When forming the columns, there is a

Openness of clear span.

very limited amount of space for placing reinforcing steel as well as embedded plates. Even though the members are precast in a shop, this should be considered if the moment connections require large amounts of reinforcing steel or welds. On the other hand, shear walls will also require either embedded plates and/or coil rods to help transfer shear from the diaphragm to the shear wall; however, there is usually sufficient length along the shear wall to adequately transfer the design forces without unusual welds or excessive congestion.

Another item to consider is the detailing of seismic collectors. If the structure has a seismic design category C or worse, then the collector loads are required to resist the special seismic loads as indicated in ASCE 7-02 Section 9.5.2.7.1. The special seismic loads require the horizontal seismic forces to be multiplied by the system over strength factor, Ω_o. (ASCE 7-02 in the table calls this factor "W_o" but in the text and normal convention is "Ω_o".) For Ordinary Reinforced Concrete Moment Frames and Ordinary Reinforced Concrete Shear Walls, the values are 3 and 2½, respectively. Again, using shear walls allows the use of a lower design force which can have a dramatic affect on the engineering design.

The deflection amplification factor (C_d,) can affect expansion joints or seismic separation between buildings. A number of parking structures are adjacent to existing buildings making seismic separation an important consideration during the design. A very flexible assembly will require a greater separation per section 9.5.2.8 of ASCE 7-02. The C_d factor for Ordinary Reinforced Concrete Moment Frames is 2½ while it is 4½ for Ordinary Reinforced Concrete Shear Walls. Even though you must amplify the deflection of the shear wall system by almost twice the amount of the moment frame, the higher stiffness of the shear walls will normally result in less deflection to accommodate than with a moment frame. If abutting buildings or expansion joints will be an issue on your project, the increased drift is an important item to consider when using moment frames.

Restraint Against Thermal Movements

Another factor to consider in selecting and designing the lateral load resisting system is the amount of restraint provided by the two systems against thermal movements. This is an area where more flexibility is an advantage. When shortening tries to occur in the length of the garage due to thermal changes, the structure is often too rigid and tension develops in the members. This force is typically perpendicular to the length of the panel and is resisted by the diaphragm shear connectors. These connectors can be under considerable stress, and cracks frequently occur around them. Taking this into account when planning the garage can help lesson the extent of the problem.

Shear wall framing is obviously very rigid and problems can be amplified with this system. The problem can be reduced by locating shear walls near the middle of the length of the building. If the driving aisle crossovers are at the ends of the garage, the last bay would not have longitudinal shear walls (at least not at interior wall lines), and would be more flexible. By using the precast walls near the ends of the building as bearing only, not a shear wall, the double-tee will be able to slide sideways slightly on its support if the connection of the double-tee to the wall is flexible. The diaphragm shear connectors must still develop a large force, but it is not near as great as when the double-tees are rigidly fastened to the walls. A rigid frame system is obviously more flexible and the forces that develop in the diaphragm shear connectors should be less.

There are similar problems with stair and elevator shafts located near the ends of the garage. If the shafts are rigid, there should be flexible connections between the shaft and the rest of the garage so that the rigidity of the shaft doesn't create tension in the garage slab when the structure tries to contract. These forces should be included in the analysis.

No matter which lateral force resisting system is chosen, these issues should receive ample consideration at the beginning of the project, as they can have a significant impact on many facets of the design and detailing.▪

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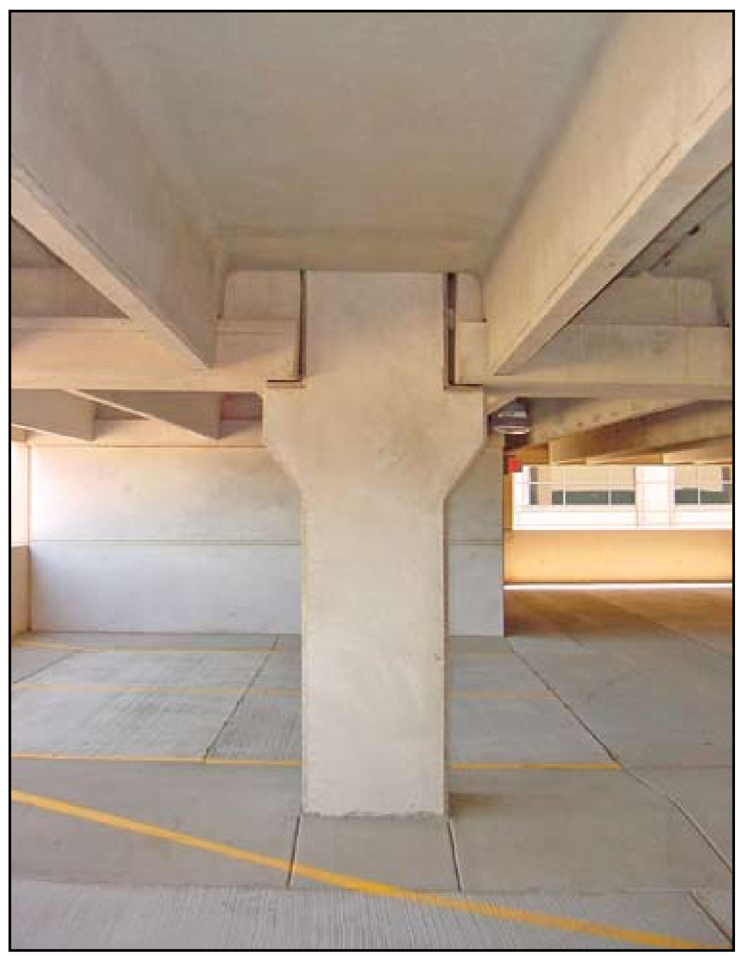

Underside of double-tee.