Double Tee Flange Failures

Study of an Existing Parking Garage

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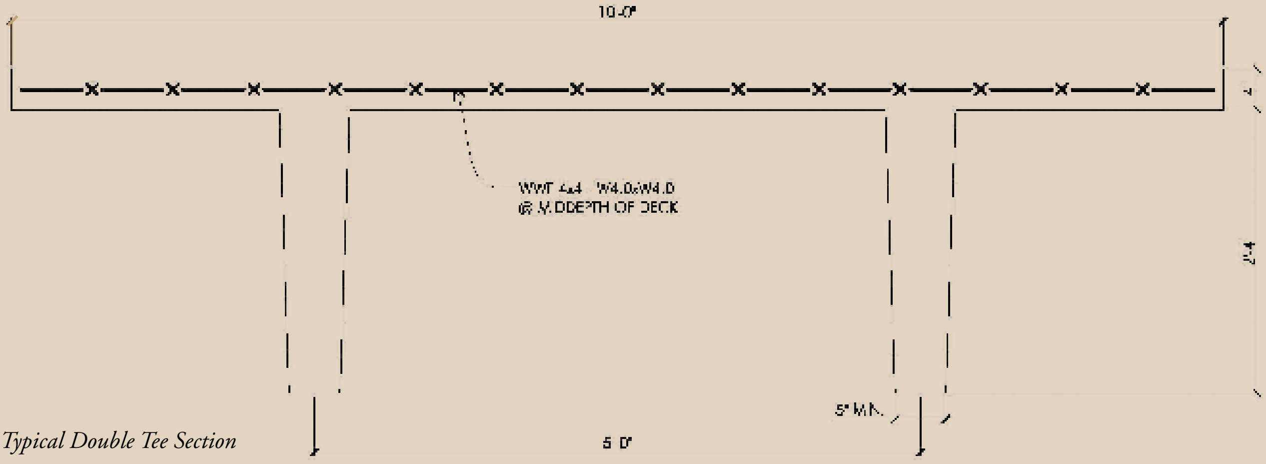

Typical Double Tee Section

There are many factors to be considered in the design of any project for a successful outcome. The designer must not only consider code issues, but also construction and maintenance procedures. Some of these issues are most clearly demonstrated in a recent forensic investigation project performed by CBI Consulting, Inc. (CBI).

This past January, CBI received a call from the Town of Natick, Massachusetts regarding one of their town-owned parking garages. Town officials reported that a portion of the upper deck cracked, and a large section of the deck appeared to be about to fall on the lower level. Both levels of the garage had been closed. The Town requested CBI to investigate the structural integrity of the structure and to assess the feasibility of reopening the facility. A program of physical exploration and testing was promptly developed and scheduled.

The parking structure in question was constructed circa 1984, and provides two levels of parking for the bustling downtown area of Natick. The upper level is supported by two simply supported spans of precast concrete double tee sections. Girders are cast in place concrete, and cast in place concrete columns are founded upon concrete spread footings. Each double tee section spans approximately sixty-two feet. Double tee section is ten feet wide and thirty-two inches deep. The flange of the tee is four inches thick and the width of the stem is a minimum of five inches. The flanges of the tee sections are reinforced with 4x4-W4xW4 welded wire fabric located near the mid-depth. The lower level of the facility is supported by bituminous pavement on grade.

The garage typically serviced passenger cars; however, no restrictions on vehicular height by gates or loads by weight postings were in place on the upper deck.

Areas of the deck were swept clean by a small sidewalk sweeper and the deck was found to be in fair condition. Due to safety concerns, town employees had knocked the damaged area of the upper deck down prior to the field investigation. This resulted in a single two foot wide by fourteen foot long hole in the middle portion of a northern span. The failed deck lay below the hole on the lower level of the garage. Other areas of the deck contained smaller holes and spalls scattered through-out the surface. Past concrete repairs were found throughout the deck and were generally in poor condition.

The rain during the investigation revealed many wet areas on the underside of the parking deck, indicating the presence of cracks. Water staining and efflorescence was also present throughout the underside of the deck. Upon excavating around several of the wet areas, the existing reinforcing was found to be generally in good condition. Further excavations around spalls and deck blow-throughs found the reinforcing mesh to be intact within one inch of concrete embedment. Observations regarding the mesh contained within the fallen 14 foot section of deck revealed corrosion along the outside edge of the mesh in several areas.

So the question becomes, "How did this happen?" First, let's review the code requirements as spelled out in the fourth edition of the Massachusetts Building Code (780CMR) which was in effect at the time of the design and construction of the garage. In Article 7, the design of a parking garage intended for passenger cars, the minimum design live load is

Existing hole in deck

shown to be 50 psf which was referenced in the garage's original design documents for the precast tee manufacturer's reference. The code also called for a 2,000-pound concentrated load distributed over a six- by six-inch square. The concentrated load requirement was not referenced in the design documents. How critical was the 2,000-pound load requirement? Is the 2,000-pound load reasonable? After all, the design live load mo-ment for a simply supported 62-foot long, 10-foot wide section carrying 50 psf is over 240 foot·kips. Meanwhile the design live load moment for a 2,000-pound concentrated load is only 31 foot·kips. This is true, but a designer must check all the components of the tee.

Failed area of deck

As previously mentioned, the flange of the tee is four inches thick with 4x4-W4.0xW4.0 welded wire fabric at the mid-depth. The flange cantilevers nearly 2 feet-4 inches from the outside edge of the tee web. Based upon a concrete compressive strength of 5,000 psi as called for in the contract documents and ASTM A-185 mesh (f_y = 65ksi), an allowable uniform live load was calculated to be 211psf according to ACI 318 load factors – far exceeding the 50 psf design requirement. Now let's look at the concentrated load requirement.

The fourth edition of 780CMR does not specify how wide of a slab area the force may be distributed. For a distribution of a concentrated load in a cantilever slab, section 3.24.5 the 17th edition of AASHTO *Standard Specifications for Highway Bridges* was referenced. Using the AASHTO loading combinations and neglecting impact, since it is assumed that vehicles traveling on the parking deck will be traveling at low speeds, it was calculated that the cantilevered slab could only resist a maximum concentrated load of 1200 pounds. This is less than the code requirements, but is the 1200 pounds adequate?

The upper level parking deck is an open structure and is subject to snow. In order to keep the upper level in service during winter in the northeast, the town would remove the snow. Speaking with town DPW employees, it was discovered that previous snow removal procedures involved using front end loaders on the deck; however, once the deck started to deteriorate, pick-up trucks equipped with a snow plow were used. Road salt was not used on the deck, but it was sanded. So, the deck was also subject to loaded sanding vehicles. Exact weights of these vehicles are not known, but it would not be a stretch to assume that the loaded truck tires exceeded the 2,000-pound requirement. The deck would most likely have been better served by designing for a truck tire loading.

The loaded vehicles could have created the hairline cracks in the deck, thereby exposing the reinforcing mesh to moister and road salts washing off parked vehicles. The water and salt would result in corrosion of the reinforcing and spalling. This conclusion is reinforced by two facts. First, chloride testing that was conducted as part of the garage study. Six core samples were recovered from the deck and tested for compression and chloride content. The water soluble chlorides (% by weight of cement) were found to be as high as 2.29%. Research indicates that the threshold at which the electrochemical process begins to corrode the reinforcing is 0.15%. This is the commonly accepted level at which the passivity of the concrete is no longer protecting the reinforcement from corrosion. Secondly, the majority of the spalls and deck blow throughs were concentrated along the cantilevered flange sections of the tees.

So, what are the lessons that can be learned from this investigation? First, a designer must not only consider all the design requirements, but also reasonable conditions that could occur during a structure's life cycle. A seemingly small component in the design could result in expensive retrofits. Secondly, there were maintenance issues that were noted during the investigation. As noted in the investigation, many of the previous repairs on the deck were not properly performed, mortar was feathered into spalled areas and separating from the deck, and joints between tee sections were in poor condition. It is also not known what coatings, if any, had been applied to the surface of the deck to help resist water infiltration. Even a perfectly designed and constructed structure requires maintenance for a long service life.▪


Underside of parking deck

Frank G. Lagodimos has been involved with the design and construction of a wide variety of structures for CBI Consulting Inc. Completed projects include building design and renovation of residential, commercial and industrial structures, as well as garages, highway bridges, communication towers, sanitary/utility structures and storage tanks.