Guest Column

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Design Considerations

Cast-in-Place Concrete Edge Barrier Walls in Parking Structures

By Gary Cudney, P.E.

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The April 2014 issue of STRUCTURE magazine featured an article in the Structural Failures column, titled *Design Deficiencies in Edge Barrier Walls in Parking Structures*, by Mohammad Iqbal, D.Sc., P.E., S.E., Esq. The article brought up important points related to the adequacy of upturned cast-in-place (CIP) concrete barrier walls supported on slab edges to withstand code-prescribed vehicle barrier loads in parking structures. We, members of the National Parking Association's (NPA) Parking Consultants Council (PCC), could not agree more that all types of vehicle barriers in parking structures must be designed, constructed, and maintained to withstand the code-prescribed vehicle barrier load in an effort to protect the health, safety and welfare of the public; however, we would like to provide clarifications to the article.

The PCC's structural committee has been actively involved in barrier wall design for decades. The PCC's *Recommended Building Code Provisions for Open Parking Structures*, published in July 1980, first prescribed that a 10,000 pound ultimate load (6,000 pound service load) located 18 inches above the floor be used as the bumper load criterion, long before any of the national model building codes adopted such a criterion.

As specialists in parking structure design and restoration, PCC members are aware of about 25 accidents in parking structures in the past 10 years where vehicle barriers failed and vehicles fell off the edge as a result, causing property damage, personal injury, or death. For the purposes of this article, failure of the vehicle barrier is defined as the barrier breaking upon impact to such an extent that it was incapable of restraining the vehicle inside the parking structure at the same level as it was parked. Concrete cracking and other barrier damage that requires repair is not considered "failure," if the impacting vehicle is kept from going over the edge. The 2014 article noted that many of the failures occurred for the following reasons:

- The parking structure was constructed when the applicable building code did not require a perimeter vehicle barrier or prescribe the design vehicle barrier load.
- Instead of a vehicle barrier, just a wheel stop or curb and either a handrail or an architectural panel were used, which together were inadequate to withstand vehicle impact.
- Concrete Masonry Unit (CMU) walls with inadequate reinforcement were used.
- Cable rail barriers with inadequate anchoring of the cable were used.
- The vehicle hit the barrier at a high speed, resulting in an impact load well in excess of the code-prescribed load.

The PCC structural committee evaluated the vehicle barrier issue and realized that vehicles today have higher bumpers than vehicles in the mid-1970s when the 10,000 pound ultimate (6,000 pound service load) vehicle impact load at 18 inches above the floor was recommended for reasons explained in a published article titled *High Bumpers Prompt Change in IBC Code* (January/February 2009, PARKING magazine). Based on its research of vehicle statistics, the PCC submitted a change proposal to the International Code Council (ICC) in 2008 to increase the bumper impact height. The ICC adopted a vehicle impact height of either 18 or 27 inches (whichever produces the more severe loading) in the 2009 *International Building Code* (IBC), as recommended by the PCC.

In its 2009 article, the PCC also recommended that significant further study of the magnitude of the code-prescribed static bumper load is required to approximate what is actually a dynamic loading condition. This committee intends to develop future recommendations based on:

- Vehicle weight,
- Vehicle speed,
- Energy absorbing mechanisms within the vehicle,
- Energy absorbing mechanisms within the barrier wall, and
- Statistical analysis of a "design" vehicle hitting the barrier at a "design" speed.

The PCC is currently seeking grant funding and a university research partner to further study these issues, so that an IBC change proposal can be developed and submitted to amend the magnitude of the vehicle barrier load, if it is found to be warranted.

The referenced 2014 STRUCTURE article discussed whether the cantilevered CIP concrete barrier wall on a slab edge can withstand the code-prescribed vehicle barrier load without brittle failure of the wall-slab corner joint. PCC members conferred to clarify the information provided in the article as follows.

1) The article stated, "Many failures occur in concrete structures because of inadequate detailing of reinforcement in joints and connections. The failure of perimeter vehicular barriers in concrete parking structures offer grim examples where numerous parking patrons have died or have suffered bodily injuries as their vehicles plunged down to the street during the past several years."

PCC members are aware of about 25 vehicle barrier failures in parking structures in the past 10 years. Based upon a review of accident records, about two thirds of these failures occurred where a CMU block wall, cable rail, or precast concrete spandrel barrier was used, and one third occurred where a CIP concrete wall was used. It is not known if these CIP concrete wall failures occurred due to inadequate detailing of reinforcement in

joints and connections or for other reasons. This data makes it clear that all types of vehicle barrier systems must be designed, constructed, and maintained to be adequate to withstand the code-prescribed vehicle barrier load.

2) The article stated, "The test results show that concrete wall-slab barrier systems do not meet the IBC's minimum threshold."

It would be beneficial to view the test results that support this statement. Concrete wall-slab barrier systems can be designed and constructed to meet and exceed IBC requirements, as indicated in item 4 below.

3) The article stated, "The issue is whether the barrier system was capable of resisting the code-prescribed 10,000 pound ultimate impact load. The evidence suggests that it does not have the capacity to resist the prescribed load. Rather, its capacity is about one-fourth of the prescribed load. As such, the barrier system has a significant design deficiency."

The capacity of the concrete wall-slab barrier system depends on many factors such as the wall thickness; slab thickness; slab perimeter wash thickness; concrete strength; and steel reinforcement amount, location (cover), and configuration. The CIP concrete wall barrier system can be designed to properly resist the code-prescribed vehicle barrier load, as indicated in item 4 below.

4) The article stated, "The assumption that the wall shear force and bending moment at the base of the wall are fully transferred to the slab through the joint region appears to have no basis."

The wall-slab joint can be capable of transferring the shear force and bending moment resulting from the code prescribed vehicle barrier load. Standard Department of Transportation bridge railing designs use an upturned wall supported on a thin slab edge similar to what is sometimes used in parking structures. Further, research by Ingvar H.E. Nilsson and Anders Losberg, published in the ASCE Journal of the Structural Division in June 1976, in a paper titled *Reinforced Concrete Corners and Joints Subjected to Bending Moment*, indicates that when a single layer of steel is used in the wall and slab with standard 90° hooks and the reinforcement ratio is less than or equal to 0.30%, the wall-slab joint is 100% efficient. However, the paper also indicates that if the reinforcement ratio exceeds 0.30%, brittle failure of the joint controls the capacity and no amount of additional reinforcing steel will help make the wall-slab joint stronger. It is good structural engineering practice to design the wall-slab joint to be ductile such that yielding of the reinforcing steel occurs prior to a sudden brittle failure of the concrete at the corner.

When using a CIP concrete barrier wall in parking structures, the following is recommended by the PCC:

- Use code-prescribed vehicle barrier load and height of impact
- Apply the principal goal of having a ductile connection, which can be obtained by considering the following:
  - o Maintain a low reinforcement ratio as described in the paragraph above
  - o Maintain code prescribed hooked bar development lengths in both the wall reinforcing, as well as the supporting slab reinforcing.
- Provide adequate horizontal reinforcement in both the wall and the supporting structure to distribute the vehicle impact load horizontally over the section of wall/slab joint used to resist the load.

We believe that this performance criteria can be achieved using an appropriate thickness of wall with a single layer or double layer of reinforcing with 90° hooks and careful

consideration of reinforcing steel cover requirements, supported on an appropriately designed slab edge (note the slab edge thickness can be a combination of the base slab thickness plus any thickness of a perimeter wash beneath the wall). Further, most often the wall-slab joint is at the edge of a post-tensioned (P/T) concrete slab where the P/T tendons (structural and temperature) and pair of P/T anchor back up bars provide additional reinforcement in the wall-slab joint that strengthens the corner beyond what laboratory tests might indicate.

5) The article stated, "To improve the joint efficiency, the concrete in the joint region and the members should be bound or confined with straps, hoops, and ties."

While the use of straps, hoops, and ties will improve the joint efficiency, they are not required for the CIP concrete wall barrier system to resist the code-prescribed vehicle barrier load, as indicated in item 4 above.

6) The article stated, "To avoid any further loss of life, it is suggested that the wall-slab system should not be used in the parking structures as a vehicular barrier."

CIP concrete wall-slab systems are a viable method of providing a safe vehicle barrier in parking structures. When properly designed, constructed, and maintained, the wall-slab system can withstand the code-prescribed vehicle barrier load without incurring the risk of catastrophic brittle failure.

7) The article stated, "Further, it is recommended that such barriers that are already in place in constructed facilities should be retrofitted."

Many existing parking structures using CIP concrete barrier walls have no need to be retrofitted, as they may be capable of resisting the code-prescribed vehicle barrier load. The PCC agrees that existing parking structures without vehicle barriers, or those which were constructed before the code included vehicle barrier requirements, should be evaluated related to the currently applicable code(s). At present, the decision to retrofit vehicle barriers that are not in compliance with the currently applicable code is at the discretion of the building owner, as the code does not require that existing structures be brought into compliance with the current code in this regard. It is suggested that engineers who are contracted to work on parking structures without vehicle barriers, or on those which were constructed in the past before the code included vehicle barrier requirements, apprise the owner that the vehicle barriers do not meet the current code and that this results in risks to parkers and the owner. The owner can make an informed decision about whether to have the vehicle barriers analyzed and retrofitted if needed to withstand the currently applicable code-prescribed vehicle barrier load. Of course, engineers are not qualified to provide legal advice to their clients, so they should refrain from doing so in this matter as well.

The article referred to an incident where a CIP concrete barrier wall failed and a picture of the failed wall was included. The inference was that the failed wall was constructed in accordance with Figure 2 in the article; however, information about the details of the wall, slab, or vehicle speed was not included. The PCC's opinion is that the length of the failed wall in the picture makes it doubtful that inadequate detailing of the wall-slab corner reinforcement was the sole reason for its failure or the cause of the failure at all. The article also included a photograph of a failed specimen tested at Banaras Hindu University in India. It would prove beneficial to know the reference and details related to the photo, including how the joint was reinforced. The article indicated that the specimen failed at 22% of the design load. In order to determine if this is correct, the following needs to be answered: "What design load is this?" and "How does it relate to the vehicle barrier design load of the IBC?"

It is agreed that the wall-slab corner detailing requires attention. However, to fix a "problem", one needs to truly understand its causes. The fact that a 6-inch wall with #4 reinforcing bars may not strictly comply with ACI 318 development length requirements and has a reinforcement ratio slightly above 0.30% does not automatically render it inadequate to resist the code-prescribed vehicle barrier load. 6-inch CIP concrete vehicle barrier walls have been constructed in many parking structures. PCC members are not aware of any failures of such walls, whose cause could be specifically attributed to the alleged inadequacy of the cited detail. The incident presented in the article may be an exception. But then, again, the relevant details of that incident were not cited.

Prior to jumping to the conclusion that all existing 6-inch CIP concrete vehicle barrier walls in parking structures require retrofitting, we recommend further study in view of ACI 318-11 Section 1.4. This section allows approval of construction "which does not conform to or is not covered by this code." The 2012 IBC has a similar provision in Section 104.11. Although some 6-inch wall details may not strictly comply with every ACI 318 provision that does not necessarily mean that it is inadequate to resist the code-prescribed vehicle barrier load. We recommend that a research project be conducted to assess the adequacy of such walls in existing parking structures.

8) The article stated, "For example, installing a downturn beam or installing an upturned beam instead of a wall can help avoid the deficiency."

While installing downturned or upturned beams at slab edges with CIP concrete barrier walls is a possible solution, it is believed that doing so may not be necessary. The added expense may not be warranted. Designing and installing a wall-slab barrier that can withstand the code-prescribed vehicle barrier load without brittle failure of the corner joint is a solution that is much more cost-effective.

9) The article stated, "Further, a singly-reinforced wall is inadequate to distribute the impact load or to resist shear properly. It is suggested to use a wall that is reinforced each way, each face and to justify rationally the impact load flow from the point of application to the underlying structure."

A properly designed CIP concrete barrier wall with reinforcing steel in a single layer can meet code requirements to transfer the shear and moment from the code required vehicle barrier load into the slab without sudden brittle failure of the concrete at the corner joint, as described in item 4 above.

Conclusion

All types of vehicle barrier systems in parking structures, including CIP concrete walls, precast concrete walls, tensioned cables, steel guard rails, and CMU walls must be properly designed, constructed, and maintained to withstand the code-prescribed vehicle barrier load. As indicated above, the PCC members believe that CIP concrete walls can safely be used for the vehicle barrier.▪

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