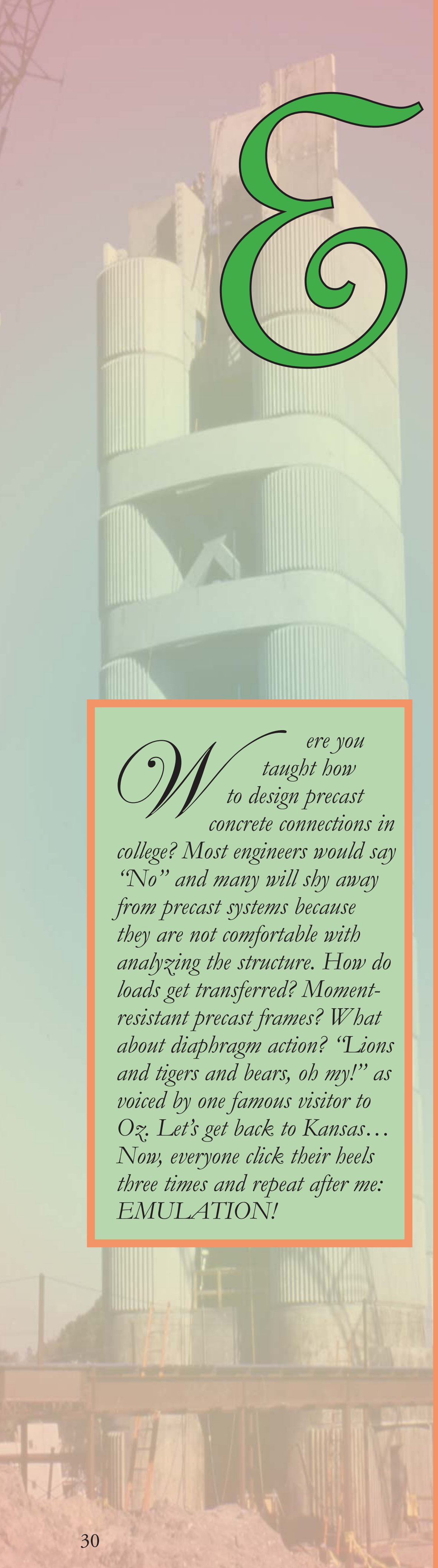

Emulative Connections for Precast Concrete

By Alvin C. Ericson

Remember when you studied reinforced concrete design? Well, now you know how to design in precast, because the latest codes now recognize a way of looking at connecting precast members to make them behave as if they were monolithically cast-in-place. It's called emulative detailing and is covered by a committee report published by the American Concrete Institute called "Emulating Cast-in-Place Detailing in Precast Concrete Structures" (ACI 550.1R-01).

Were you taught how to design precast concrete connections in college? Most engineers would say "No" and many will shy away from precast systems because they are not comfortable with analyzing the structure. How do loads get transferred? Moment-resistant precast frames? What about diaphragm action? "Lions and tigers and bears, oh my!" as voiced by one famous visitor to Oz. Let's get back to Kansas… Now, everyone click their heels three times and repeat after me: EMULATION!

Codes Allow It

The building codes have also started to mention emulation. It started with the 1994 National Earthquake Hazard Reduction Program (NEHRP) Recommended Provisions issued by the Building Seismic Safety Council (BSSC). They divided the world of precast connections into "emulative" and "jointed" types. When you were thinking of those lions and tigers, those were the jointed connections that only experienced precast engineers can tame.

The 1997 Uniform Building Code (UBC) was the first to mention "monolithic emulation" and it has evolved into the subsequent International Building Code (IBC 2000 & 2003). These codes only allowed emulation for frames, but then, ACI 318-02 came out with provisions for walls (Chapter 21.8.1 & 21.13.1) in addition to frames (Chapter 21.6.1 & 2). Dr. S.K. Ghosh wrote an article for Structure Magazine in April 2003 that gives a road map to the codes with regard to precast. In this article, we will take a closer look at emulative detailing.

Simple Concepts

So, now you know that it's allowed by code, what is it, exactly? Emulation or emulative detailing is a way of connecting precast members so they act as if they were monolithically cast-in-place (CIP). Think about how CIP works. You have concrete and reinforcing steel. The steel is tied up in cages and put in forms, and concrete is poured around the steel. Your design methods presume continuous materials, but forming and casting a structure all in one pour is usually highly impractical.

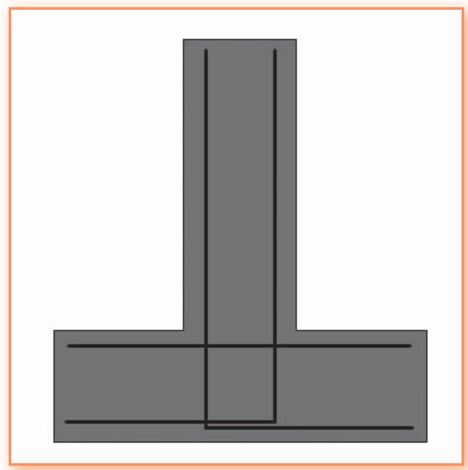

Figure 1: Monolithic Design Presumption

Concrete structures are cast in stages. At each stage, the reinforcing steel and the concrete is "connected" usually by lapping steel and placing wet concrete against cured material.

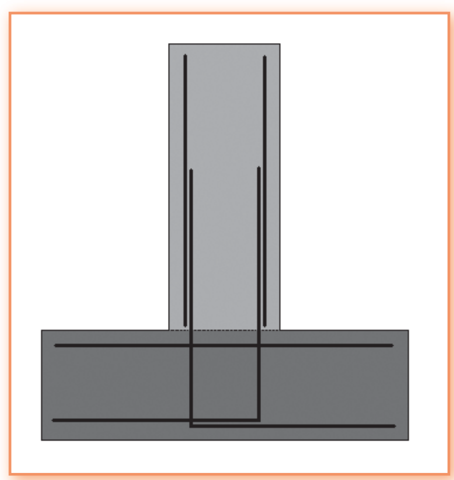

Figure 2: Lap Slices and Cold Joints typical in CIP Construction

the beam ends to mesh while the main vertical column bars can pass through to the next level. This is also a detail used in Japan where congested reinforcing is a problem and making smaller individual column and beam segments are more desirable for trucking along narrow streets to the job site.

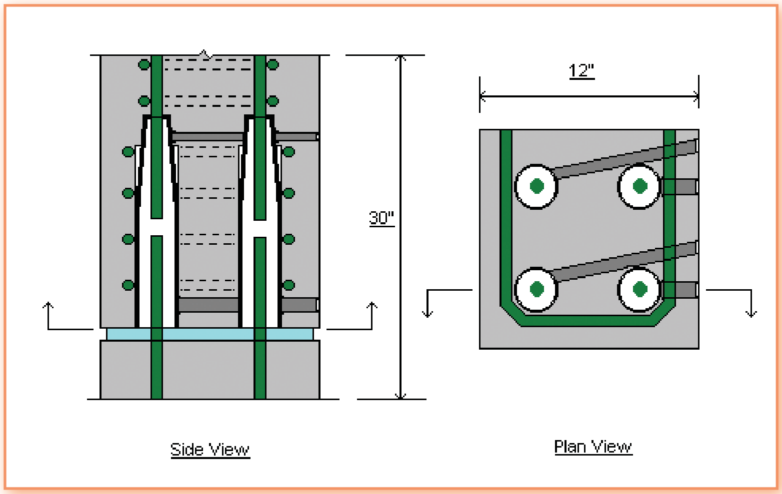

Figure 3a: Grouted splice sleeve elevation and plan view

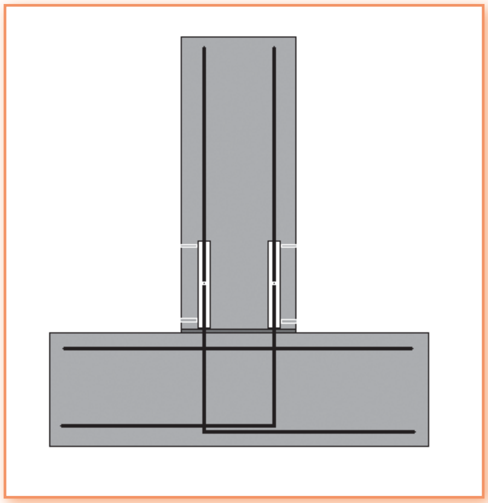

Figure 3b: Grouted splice sleeve at base of column or wall

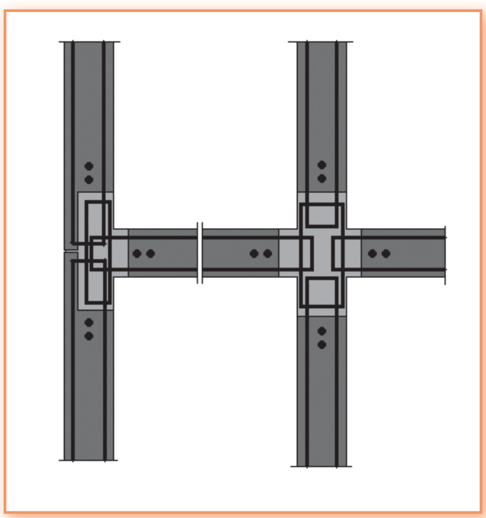

Figure 3c: Horizontal lapped or hoop splice

How else can rebar be connected? There are three methods: lapping, welding and mechanical splices. How about concrete? You add more and fill in the space. This might be the next pour up a wall or column, or a closure pour in between two previous castings. It could also be a grouted joint if the space is too small to allow large aggregate.

Pretty much any combination of these methods can produce an emulative precast connection. However, some are more practical than others depending on the location in the structure. For vertical bars crossing horizontal joints, grouted mechanical splice sleeves are particularly well suited to connect columns and walls.

For horizontal bars, either couplers, or lap or hoop splices are usually employed. These bars could be in beams and floor slabs to create live load continuity or a full moment-resisting joint. They could also be running between wall panels running up a vertical joint to transfer shear forces. *Figure 3c* is typical of many Japanese residential apartment buildings which use precast bearing wall panels that are connected in the corners of the walls with a CIP closure. The main vertical bars are not in the closure, but adjacent in the ends of the precast.

Now this would be a full monolithic emulation of a CIP design. Where seismic or vertical shear issues are not severe, tying the walls with a few welded plates is a more common solution. We have also seen this connection used just at the top of the wall as you would use a bond beam in a block wall.

Another variation is the CIP closure at the column. This allows reinforcing steel from

Key Points

As long as you are connecting each rebar separately, and filling the space with concrete or grout, the result should emulate CIP and be deemed “emulative”. The rules of CIP detailing apply. Maintain cover, spacing and development lengths. Mechanical couplers and headed reinforcement can be extremely useful in minimizing congestion, but the extra width of the coupler must be accommodated and the rebar pattern might be pushed inward affecting the number and size of the bars.

Properly conceived connections can occur anywhere in the structure. Joints can be in plastic hinge zones or the point of inflection in a beam or mid-span. The decision to locate a connection depends more on constructability issues: casting dimensions, transportation, crane capacity, etc.

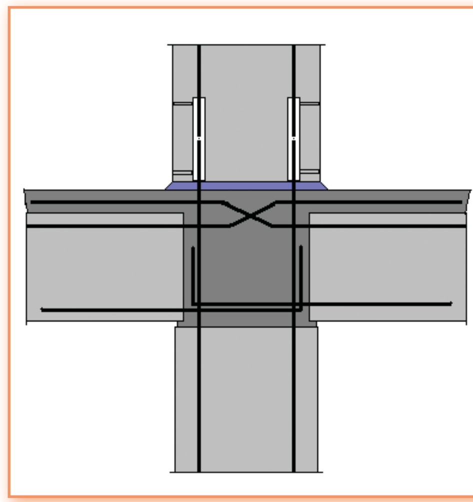

Figure 4: CIP closure at column beam ends

Engineers need to remember that if they are using a mechanical coupler to make the rebar connection, there are two levels of performance required depending on the seismic design and location of the coupler. The old 125% of specified yield is now called a Type 1 coupler. It can be used anywhere in the structure as long as you are not required to use Chapter 21 of ACI 318. As soon as you are into seismic detailing, Type 1 is limited to non-plastic hinge areas. If you place the connection in an anticipated plastic hinge, you must use a Type 2 coupler.

Continued on next page

Figure 5: MGM Grand Hotel spandrel connection

Type 2 couplers have different requirements depending on the code being used. ACI-318-05 in paragraph 21.2.6.1(b) states that it "shall develop the specified tensile strength of the spliced bar". For ASTM A615 Grade 60 bars, 100% of specified tensile equals 150% of specified yield. Note that for ASTM A706 Grade 60 bars, 100% of specified tensile equals 133% of specified yield.

To further complicate your life, UBC-97 and the subsequent IBC codes have adopted a standard for Type 2 that requires 160% of specified yield making it the most stringent. The ICC Evaluation Service also imposes a regimen of cyclic testing to gain their acceptance for Type 2 (but not for Type 1).

With lap splices, you need to follow the current code rules for lap lengths which can be a whole lot more complicated than the previous discussion on couplers. With the price of rebar hitting higher levels every day, couplers are becoming a more viable option in many situations, not just emulation.

The rules for welding are laid out in the AWS D1.4 Structural Welding Code–Reinforcing Steel. While I would recommend A706 steel if any welding is anticipated, the AWS code gives the requirements for welding any rebar. Generally, I would reserve welding rebar for repairs and fixes that are necessitated by errors in the field.

Applications in Real Projects

While emulation is a relatively new term, the precast concrete industry has been doing emulative connections since the beginning. Lapped bars in closure pours are a standard for the ends of double tees meeting spandrel beams or double ledger beams in parking structures. Connections of horizontal bars are most often accomplished with lap splices in closure pours.

Back in Oz, the newest "Emerald City" is the MGM Grand Hotel in Las Vegas. It was rebuilt in the early 1990's. It used a total precast structural system for the main hotel wings, which were 30-story in height to provide over 5000 rooms. The precast exterior spandrel shown in *Figure 5* was connected with lap splices in closure pours for the horizontal beam bars, and grouted splice sleeves for the vertical column bars. The precast unit was an H-shape that placed the connections outside the intersection of the column and beam to simplify the rebar detailing.

The floor system was the widest hollow core plank (12-foot) ever to be made. It was "untopped" and set on solid precast load bearing shear walls connected with vertical bars connected with sleeves. In order to simplify the process of grouting, they used a single 5000-psi pea-stone grout in the shear keys of the plank, the end bearings over the walls, the pocket shear connections to the spandrels and the horizontal closure pours between spandrels.

Figure 6a: Precast frames in Ohkawabata Tower, Tokyo

Figure 6b: Ohkawabata River City 21 Tower (on left), Tokyo

This type of framing was also used on the first splice sleeve project, the 38-story Ala Moana Hotel in Honolulu in 1970. Total precast framing allowed this structure to be completed in nine months to take advantage of a boom in tourist travel to the island.

Bridge engineers discovered emulative detailing in the late 1980's. They were using lapped and hooked bars in closure pours over piers well before then, but connecting vertical bars was demonstrated to be a viable solution to create precast piers in the Edison Bridge in Fort Myers, Florida.

The innovative H-column used in the Edison Bridge had 12-inch thick flanges and web with two #14 bar in the center end of each leg end, thus providing outstanding cover for corrosion protection. The pier cap was an inverted U-shape to save weight. The columns were erected at a rate of six per day with the caps following the next day. That's three piers every two days and it resulted in savings of two months on the overall construction schedule for each of the two bridges.

Engineers doing restoration work also discovered that precasters could cast members to duplicate historic bridges, and allow them to be re-built with modern materials. The Castlewood Canyon Arch Bridge Restoration recently won awards for innovative use of precast and other new repair materials from both the Precast/Prestressed Concrete Institute and the Portland Cement Association.

The precast deck panels utilized hoop bars while the spandrel columns and floor beams were connected with splice sleeve couplers.

There have been numerous applications in all types of building and bridge structures: air traffic control towers, stadiums, housing, etc. The potential is limitless. I often say to engineers that if you can design it in concrete, I can turn it into precast.

People often ask about the economics of emulative detailing. The real question is the benefit of precast concrete. The cost of these connections is usually about the same as welded, bolted or lapped splices except in high seismic design where there is usually a demonstrable savings. Emulative connections can save in the area of patching and finish work as many are designed as "blind" connections. The major benefits of precast are in quality of finished product and speed of construction reducing the amount of field labor.

When you pour a wall or column in place, there is all the activity of building reinforcing cages, setting forms and then waiting for curing to remove shoring. Precast members are erected immediately, the connections grouted and the braces removed the next day if necessary.

So there is no need to be a "cowardly lion" when you see the next project where precast would help the schedule or make for a higher quality finished product. Just like the lion, you already have it in you. You already know how to do CIP design: just emulate it in precast!▪

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Figure 8: Castlewood Canyon Arch Bridge, Colorado

Figure 7: Edison Bridge piers curing construction

Figure 9: Castelwood Canyon precast deck panels