ECONOMIC ANALYSIS

Mechanical Butt Splices
vs.
Lap Splicing

in Reinforced Concrete Construction

Prepared for ERICO,® Inc.
Solon, Ohio

Study Conducted by:

Cagley and Associates, Rockville, MD

James R. Cagley and Richard Apple

ECONOMIC ANALYSIS

Mechanical Butt Splices

vs.

Lap Splicing

in Reinforced Concrete Construction

OBJECTIVE

The study was conducted to determine the actual in-place cost of reinforcing steel lap splices vs. mechanical butt splices in structural frames; then make a realistic comparison based on economic and structural benefits.

HISTORICAL BACKGROUND

Since the beginning of reinforced concrete use, lap splices have been the accepted method of joining bars. Functionally, with small bar sizes, relatively low yield stresses, and when buildings rarely exceed 15 stories, laps performed adequately. Today, reinforced concrete buildings are reaching ever higher into the sky. The Petronas Towers in Kuala Lumpur recently topped out over 100 stories.

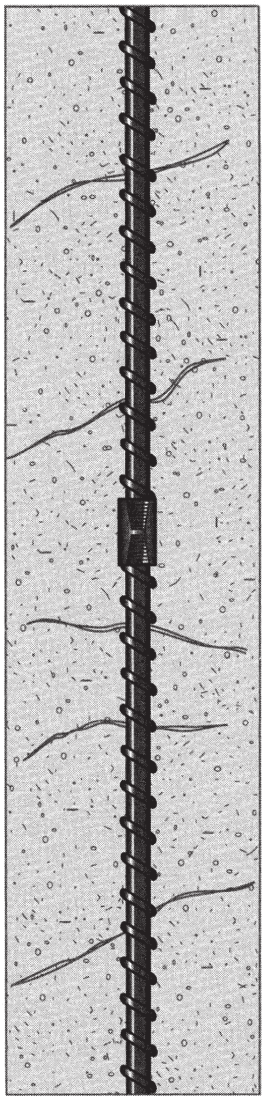
Common design practice for structural framing uses bar sizes from #8 through #11 with yields of 60 ksi or 75 ksi. Concrete strengths of 8000 psi to 12,000 psi are accepted by code and increasingly used. Use of higher strength concrete, which is more susceptible to splitting failures, allow for shorter lap lengths, creating a questionable condition. Conversely, premium-priced epoxy coated bars required longer lap lengths.

Research work on reinforcing steel convinced ACI to limit the use of lap splices to #11 and smaller bars. The 95 ACI Code forbids lap splices in tension tie members (12.15.5) and prohibits lap splices for plastic hinge regions (R21.3.2). The model code bodies (BOCA, UBC, SBC) adhere to these same requirements. These decisions by responsible code bodies bring into question the integrity of the lap splice principle, which asks concrete to transfer loads in tension and shear. Concrete is notably poor in both these properties.

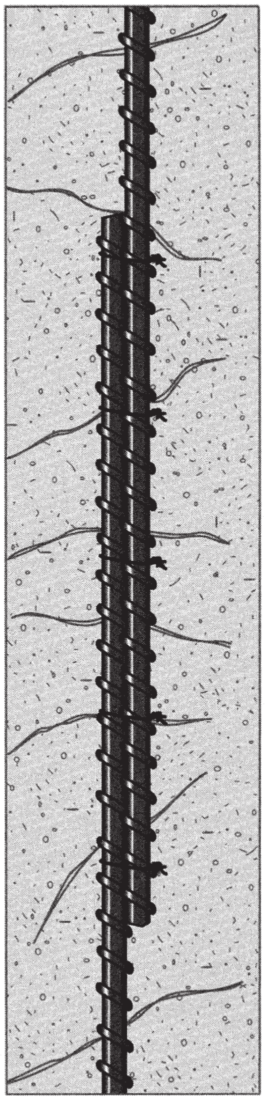
DISCUSSION

Cagley and Associates recently studied two different structures which were under design in their Rockville, MD office. The first structure was a 12-story parking garage in Harrisburg, PA. The second was a 3-story chemistry lab for the National Institute of Standards and Technology in Washington D.C. Each structure utilized approximately 10,000 (cy) of concrete. The two structures used framing designs based on ACI 318-95 Chapter 12. Only the column bars in NIST required splicing, as the beams utilized continuous reinforcing steel. Lap splices were used on the parking garage. Mechanical butt splices where used on the NIST chemistry lab because lap splicing would have pushed the steel/concrete ratio to over 8% in the lap splice zone. A ratio of over 8% is prohibited by ACI Code.

To determine installation labor costs, five rebar placing contractors were questioned on comparative costs of installing lap splices and mechanical threaded butt splices. The consensus was that the installation costs were equal. Also, only the column bars were analyzed. Had the beams been considered (which normally have longer lap lengths) the lap splice costs would have been higher than reported. The cost analysis is summarized later in this report.



Mechanical butt splicing provides the assurance of maintaining load path continuity of the structural reinforcement independent of the condition or existence of the concrete.



Lap splices depend on concrete for strength, therefore lacking structural integrity and continuity in concrete construction.

STRUCTURAL CONSIDERATIONS OF MECHANICAL BUTT SPLICES

The most important benefit of using mechanical butt splices is the assurance of maintaining load path continuity of the structural reinforcement independent of the condition or existence of the concrete. Code mandates 25% higher strength for the coupled bar than the design yield strength. This ensures performance well into the strain hardening region.

In seismic regions, the dynamic demands placed on structures are extreme. Mechanical splices maintain the structural integrity when bars are stressed into the inelastic range. Lap splices often infringe into the plastic hinge region, violating code requirements. Mechanical splices can be easily located outside these high stress regions.

In snowbelt and coastal regions, corrosion of rebar due to chlorides lead to delamination and spalling of the concrete cover, rendering the lap splice ineffective. When the concrete is gone, a lap splice has failed.

A tragic example of the effect of loss of load path continuity is found in the ASCE-FEMA report[1] on the Murrah Building in Oklahoma City. A catastrophic failure of the structure resulted from the removal of one column. The investigators state, "up to 85% of the progressive collapse could have been avoided had the structure used special moment frames". With the use of mechanical butt splices, special moment frames incorporate continuous reinforcement and load path continuity.

Additionally, butt splices reduce congestion in the reinforcement. Congestion caused by laps, which double the steel/concrete ratio, creates problems not only while placing the bar, but also during concrete consolidation. Eliminating laps also frees space for the post tensioning operation.

ECONOMIC CONSIDERATIONS OF MECHANICAL BUTT SPLICES

Federal Executive Orders 12699 and 12941 mandate seismic safety design in any federally assisted or regulated new building construction and any existing federally owned or leased buildings. Both of these Executive Orders are part of a move to bring all buildings occupied by any federal department or agency up to seismic standards, regardless of geographic region. Seismic design includes special moment frames with continuous load path in the rebar by use of mechanical butt splices.

The federal government is the largest renter of office space in the country. Owners of existing buildings currently renting or planning to rent to a government agency should be aware that compliance with these Executive Orders are mandatory.

Many potential building buyers are insisting on pre-purchase inspections by a structural engineer to determine the integrity of the building or compliance with seismic code. Code bodies are also considering additional structural integrity requirements. A buyer will often times pass on the purchase if the building does not meet these code standards. The current owner may incur the expense upgrading the structure or live with the loss of value.

A move is underway by structural engineers in California to ask large insurance companies for reduced premium rates on buildings designed and built with seismic frames. The same principle as that of a building with a superior fire sprinkler system rates a lower premium. If this goal is accomplished, the lower premium over the life of the structure will be a large savings.

CONCLUSION

The results of this study have shown that the cost associated with upgrading a structure by using mechanical butt splices was less than 0.2 percent of the total cost of the structure (refer to cost charts on previous pages). As noted previously, the analysis only focused on the column bars and did not consider the beam steel, making this a worse case scenario.

The added structural and economic advantages of mechanical splices over laps make the benefit-to-cost ratio extremely attractive. Mechanical splices give the structure added toughness and load path continuity that laps cannot offer.

MORE RESEARCH REQUIRED

A call for more research is recommended on the performance of lap splices when used with high strength materials.

REFERENCE

(1) "The Oklahoma City Bombing: Improving Building Performance Through Multi-Hazard Mitigation" ASCE-FEMA, August 1996

CAGLEY & ASSOCIATES

Cagley & Associates is a nationally renowned structural engineering firm located in Rockville, Maryland. The firm is affiliated with the Cagley Group, a firm with engineers registered in all fifty states, who consult on architectural and structural projects around the world.

The firm's managing principal, James R. Cagley, is a fellow of the American Concrete Institute, Chairman of ACI 318 Standard Building Code Committee, and a former member of the Board of Directors. He has presented numerous papers dealing with systems construction, cast-in-place and post-tensioned concrete, and earthquake resistant design. He was a consultant to the Applied Technology Council that developed the national earthquake resistant design criteria. The author, Richard Apple, is vice president and project manager for Cagley & Associates and is responsible for the analysis, design and production of construction administration and the evaluation and selection of structural systems for new projects.

PNI Garage: Total cost $8.5 million

Cost for lap splice option (used): $139,653

Cost for butt splice option: 158,583

Difference: 18,930

Additional coupler cost: .... $18,930 = 0.00223

Total project cost: $8,500,000

(0.00223 increase in overall cost to use mechanical splices for added structural benefits.)

PROJECT NAME: *PNI Garage*

Column Type	No. of Column Type	Bar Size	Bar No.	Length of Lap (inches)	Weight of Bar (lbs.)	Total Weight of Laps (lbs.)
A-1	5	8	8	35	2.67	312
A-1	4	9	8	44	3.4	399
A-1	3	11	8	63	5.312	669
A-2	5	8	8	35	2.67	312
A-2	4	9	8	44	3.4	399
A-2	3	11	8	63	5.313	669
A-6	6	11	18	97	5.313	4638
A-6	5	11	22	89	5.313	4335
A-6	1	11	28	89	5.313	1103
A-7	4	8	8	35	2.67	249
A-7	4	9	8	44	3.4	399
A-7	3	11	8	63	5.313	669
B-1	4	11	8	69	5.313	978
B-1	2	11	12	69	5.313	733
B-1	4	11	16	89	5.313	2522
B-1	2	11	18	89	5.313	1419
B-7	3	11	3	69	5.313	275
B-7	2	11	11	69	5.313	672
B-7	3	11	14	89	5.313	1655
B-7	3	11	18	89	5.313	2128
C-1	4	11	12	97	5.313	2061
C-1	5	11	16	93	5.313	3294
C-1	2	11	18	89	5.313	1419
D-1	4	11	12	97	5.313	2061
D-1	5	11	16	89	5.313	3152
D-1	2	11	18	89	5.313	1419
C-6	5	11	18	97	5.313	3865
C-6	2	11	20	93	5.313	1647
C-6	2	11	24	89	5.313	1891
C-6	2	11	32	89	5.313	2522
C-7	5	11	12	97	5.313	2577
C-7	3	11	18	89	5.313	2128
C-7	3	11	22	89	5.313	2601
D-7	5	11	12	97	5.313	2577
D-7	3	11	18	89	5.313	2128
D-7	3	11	22	89	5.313	2601
D-6	5	11	14	97	5.313	3006
D-6	4	11	16	89	5.313	2522
D-6	2	11	22	89	5.313	1734
E-1	5	11	12	97	5.313	2577
E-1	4	11	16	89	5.313	2522
E-1	2	11	18	89	5.313	1419
F-1	5	11	12	97	5.313	2577
F-1	4	11	16	89	5.313	2522
F-1	2	11	18	89	5.313	1419
E-6	5	11	14	97	5.313	3006
E-6	4	11	16	89	5.313	2522
E-6	2	11	18	89	5.313	1419
E-7	5	11	12	97	5.313	2577
E-7	3	11	17	89	5.313	2010
E-7	3	11	22	89	5.313	2601
F-6	6	11	14	97	5.313	3608
F-6	4	11	16	89	5.313	2522
F-6	2	11	18	89	5.313	1419
F-7	7	11	12	97	5.313	3608
F-7	2	11	18	89	5.313	1419
F-7	3	11	22	89	5.313	2601
G-1	6	11	12	97	5.313	3092
G-1	4	11	16	89	5.313	2522
G-1	2	11	18	89	5.313	1419
G-6	6	11	18	97	5.313	4638
G-6	2	11	20	93	5.313	1647
G-6	2	11	24	89	5.313	1891
G-6	2	11	32	89	5.313	2522
G-7	6	11	12	97	5.313	3092
G-7	3	11	16	89	5.313	1891
G-7	2	11	22	89	5.313	1734
H-1	7	8	8	35	2.67	436
H-1	4	9	8	43	3.4	390
H-1	3	11	8	63	5.313	669
H-3	7	8	8	35	2.67	436
H-3	4	11	8	66	5.313	935
H-3	3	11	12	89	5.313	1419
G-5	2	8	8	32	2.67	114
G-6	2	8	8	32	2.67	114
G-9	2	8	8	32	2.67	114
K-7	4	11	8	69	5.313	978
K-7	2	11	12	97	5.313	1031
K-7	4	11	14	93	5.313	2306
K-7	3	11	18	89	5.313	2128
L-1	7	8	8	35	2.67	436
L-1	4	9	8	42	3.4	381
L-1	3	11	8	63	5.313	669
L-4	5	8	8	35	2.67	312
L-4	6	11	8	69	5.313	1466
L-4	3	11	12	89	5.313	1419
L-6	8	11	18	97	5.313	6184
L-6	4	11	22	89	5.313	3468
L-7	9	11	8	69	5.313	2200
L-7	3	11	12	89	5.313	1419
J-4	1	8	8	32	2.67	57
Total weight of laps, all column types						**165610**

NIST Chemistry Lab: Total cost $52 million

Cost for lap splice option: $155,719

Cost for butt splice option (used): 221,092

Difference: 65,373

Additional coupler cost: .... $65,373 = 0.00126

Total project cost: $52,000,000

(0.00126 increase in overall cost to use mechanical splices for added structural benefits.)

PROJECT NAME: *NIST Chemistry Building*

Column Type	No. of Column Type	Bar Size	Bar No.	Length of Lap (inches)	Weight of Lap (lbs.)	Total Weight of Laps (lbs.)
1	34	10	32	56"	20.08	21847
2	2	10	32	56"	20.08	1285
3	1	10	30	56"	20.08	602
4	2	9	18	45"	12.75	459
5	2	10	38	56"	20.08	1526
6	1	8	24	35"	7.8	187
7	2	10	18	56"	20.08	723
8	26	10	18	56"	20.08	9397
9	34	10	12	56"	20.08	8193
10	36	10	18	56"	20.08	13012
11	13	10	12	56"	20.08	3132
12	2	10	18	56"	20.08	723
13	2	8	24	35"	7.8	374
14	1	10	24	56"	20.08	482
15	1	8	18	35"	7.8	140
16	7	8	16	35"	7.8	874
17	52	8	18	35"	7.8	7301
18	1	8	18	35"	7.8	140
19	2	8	24	35"	7.8	374
20	2	8	24	35"	7.8	374
21	1	8	24	35"	7.8	187
22	1	8	24	35"	7.8	187
23	34	10	12	56"	20.08	8193
24	5	8	16	35"	7.8	624
25	1	8	24	35"	7.8	187
26	1	8	24	35"	7.8	187
27	1	8	24	35"	7.8	187
28	6	10	12	56"	20.08	1446
29	2	10	12	56"	20.08	482
30	4	10	12	56"	20.08	964
31	1	10	12	56"	20.08	241
32	1	8	18	35"	7.8	140
33	1	8	24	35"	7.8	187
34	1	10	32	56"	20.08	643
35	1	10	32	56"	20.08	643
36	1	10	24	56"	20.08	482
37	1	8	12	35"	7.8	94
37	1	10	4	56"	20.08	80
38	1	10	4	56"	20.08	80
39	1	8	10	35"	7.8	78
40	1	8	4	35"	7.8	31
41	1	8	10	35"	7.8	78
42	1	8	18	35"	7.8	140
43	1	8	18	35"	7.8	140
44	1	8	4	35"	7.8	31
45	1	8	4	35"	7.8	31
46	1	10	4	56"	20.08	80
47	1	8	4	35"	7.8	31
48	1	8	12	35"	20.08	241
49	1	8	24	35"	7.8	187
50	1	10	12	56"	20.08	241
51	2	8	16	35"	7.8	250
52	2	10	12	56"	20.08	482
53	1	8	24	35"	7.8	187
54	1	10	32	56"	20.08	643
55	1	8	18	35"	7.8	140
Total weight of laps, all column types						**89394**