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Industry survey results on the use of prestressing strand lifting loops

- This paper provides a compilation of the results of a survey conducted to determine typical precast concrete industry practices related to the use of prestressing strand lifting loops for lifting structural members.
- The majority of precast concrete producer respondents rely on the *PCI Design Handbook: Precast and Prestressed Concrete*, as well as previous practice and engineering judgment, to ensure safe lifting-loop practices.
- Survey results show general conformance to the recommendations of the *PCI Design Handbook* for ½ in. (13 mm) diameter strand loops but variability in many lifting-loop design parameters.

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Cut-off or waste prestressing strand (ASTM A416/A416M[1]) is often used to lift precast concrete elements at the casting yard and project site. These pieces of strands are mechanically bent into loops and cast into the concrete at the necessary embedment and projection above the surface to ensure safe lifting of the element. Prestressing strands are more commonly used than other lifting anchors because they are readily available and exhibit high strength and ductility properties, as well as being flexible and economical. Lifting-loop capacity depends on, but is not limited to, the following parameters:

- strength and condition of the strand
- length and configuration of embedment
- diameter and shape of the rigging element engaging the loop
- type and strength of concrete
- lifting angle

Precast concrete manufacturers are typically responsible for ensuring an adequate lifting-loop design by implementing a safety factor to prevent strand slippage and/or strand failure. In the absence of published data, precast concrete producers' tests and experience (which were not previously readily available) dictate strand loop design capacities and detailing.

In response to this lack of knowledge sharing and consensus within the precast concrete community and as part of a PCI-funded Dennis R. Mertz Fellowship, a survey was sent to PCI-certified precast concrete producers of beams and girders in April 2019. The survey was designed to determine typical industry practices related to the use of prestressing strand lifting loops for lifting structural members. Approximately 125 producers were contacted and 35 responses were received. Of these 35 respondents, 60% produce bridge products, 69% produce building products, and 14% typically produce other products, such as precast concrete pavement and architectural elements. Eighty-six percent of the respondents typically use prestressing strand as lifting loops. Those that do not use these loops for lifting use manufactured lifting embedments, such as coil inserts or aircraft cable loops. This article provides a compilation of the raw survey results, along with commentary based on literature published by PCI and others. Because none of the respondents answered every question, the number in parentheses after each question indicates the number of respondents for that specific question. Future work on the fellowship is intended to yield a separate paper with recommendations on the safe use of strand lifting loops.

Survey results

Typical lifting-loop practices

1. **Has your company performed testing to determine safe lifting-loop capacities? (32)**

    - yes: 38%
    - no: 63%

    Some of the respondents who have not performed testing indicated that they use the following methods to ensure adequate lifting-loop capacities (19 respondents):

    - *PCI Design Handbook* recommendations: 95%
    - engineering judgment: 74%
    - previous practice: 89%
    - other: 11%

2. **Has your company performed testing to determine development lengths of lifting loops? (31)**

    - yes: 10%
    - no: 90%

    Some of the respondents whose companies have not performed testing indicated that they use the following methods to ensure adequate development lengths (27 respondents):

    - *PCI Design Handbook* recommendations: 78%
    - engineering judgment: 59%
    - previous practice: 70%
    - other: 11%

Commentary The majority of precast concrete producers rely on the *PCI Design Handbook*,[2] as well as previous practice and engineering judgment, to ensure safe lifting-loop practices. PCI's *Manual for Quality Control for Plants and Production of Structural Precast Concrete Products* (MNL 116)[3] states, "Lifting devices shall be capable of supporting the element in all the required positions utilized during the course of manufacturing, storage, delivery and erection. The establishment of safe load limits for lifting inserts or devices shall be established by full-scale testing to failure that is performed by a licensed professional engineer." PCI's *Erector's Manual: Standards and Guidelines for the Erection of Precast Concrete Products* (MNL 127)[4] originally provided a table with capacities of ½ in. (13 mm) diameter strands for single, double, and triple loops. This table was removed in the 1999 update of the manual.

Instead of full-scale physical testing, the *PCI Design Handbook*[2] provides some recommendations for lifting-loop design. This includes a 24 in. (610 mm) minimum loop leg embedment, a hook diameter of at least four times the diameter of the strand, and a minimum bend diameter of 2 in. (51 mm). A safe load of 10 kip (44.5 kN) is specified for ½ in. (13 mm) diameter, 270 ksi (1860 MPa) strand loop that satisfies the previously stated recommendations. No guidance is provided for safe working loads of 0.6 in. (15 mm) diameter strand, which is commonly used in precast and precast, prestressed concrete construction and especially for bridge members.

The "other" responses in the survey indicated PCI testing and Moustafa[5] testing as sources of guidance. Very few experimental data pertaining to lifting-loop capacity have been published, with the primary study published in a 1974 technical bulletin by Concrete Technology Associates, commonly referred to as the Moustafa test.[5] This work included 192 strand pull-out tests using 6000 psi (41,370 kPa) concrete and 80 tests using 3000 psi (20,690 kPa) concrete. In addition to ½ in. (13 mm) diameter strand, $^{7}/_{16}$ and $^{3}/_{8}$ in. (11 and 9.5 mm) strands were also tested. No 0.6 in. (15 mm) diameter strands were tested because this strand size did not exist at the time. The tests considered different surface conditions (bright and rusted), development lengths, and strand embedment configurations (straight, broom, and 90-degree bend). Multiple loops as well as inclined loads were also tested.

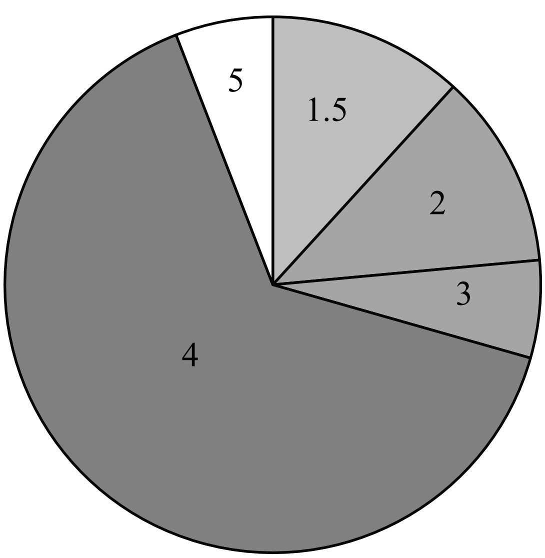
3. **How does your company determine the safe working capacity of the lifting loop? (31)**

    - special factor of safety: 65%

- dynamic loading factor: 26%
- anticipate extra force required to remove member from its forms: 42%
- other: 29%

Commentary The *PCI Design Handbook*[2] recommends a safety factor of 4 against slipping or strand breakage. Table 8.3.1 of the handbook provides equivalent static load multipliers to account for stripping and dynamic forces due to suction between the product and the form. These factors are not to be used concurrently with the safety factor of 4; it is presumed that this safety factor already encompasses these other factors. The safety factor also accounts for variability in parameters such as strand bond quality and concrete compressive strength. Most respondents (approximately 71%) use the recommended factor of 4. Approximately one-quarter of the respondents use values below 4, contrary to the *PCI Design Handbook's* recommendation.

Those that indicated "other" methods for ensuring safe working capacities listed PCI testing and charts provided by the Illinois Department of Transportation (IDOT) as alternative methods for determining safety factors. The IDOT *Bridge Manual*[6] provides relatively detailed guidance on the location, number, and embedment depths for prestressing strand lifting loops, which was validated experimentally in a study conducted by Kuchma et al.[7] for the Illinois Center for Transportation.



Distribution of safety factors typically used by survey respondents.

4. Do you heat/steam-cure? (28)

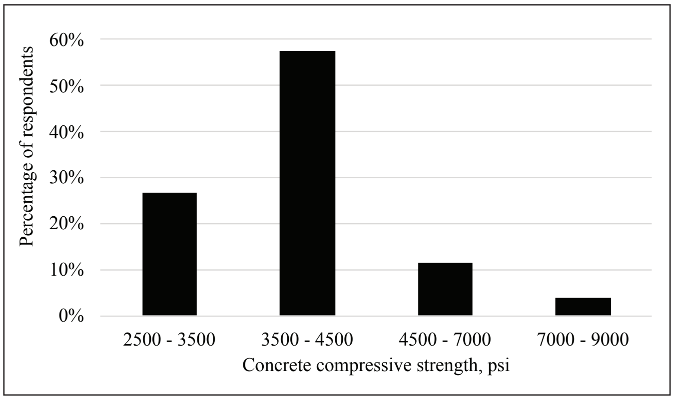
- yes: 68%
- no: 32%

5. What is the typical release strength you use? (24)

- 2500 psi (17,240 kPa) or less: 8%
- 3500 to 4000 psi (24,130 to 27,580 kPa): 38%
- 4000 to 5500 psi (27,580 to 37,920 kPa): 29%
- 5500 to 7000 psi (37,920 to 48,270 kPa): 33%
- 7000 (48,270 kPa) and above: 13%

Commentary The reported release strengths depend on the type of products that each producer fabricates. Some respondents answered this question multiple times, presumably for different types of products.

6. What is the minimum required concrete strength that must be achieved before lifting from forms? (27)

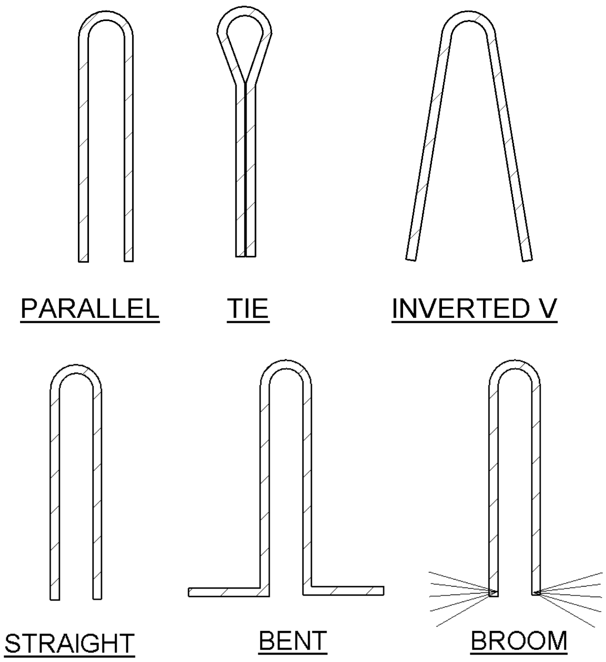


Summary of the responses for minimum concrete strengths that must be achieved before lifting structural members from their forms.

Commentary The most common strength for stripping components from the forms is in the range of 3500 to 4500 psi (24,130 to 31,030 kPa). Strengths as low as 2500 psi (17,240 kPa) were reported. MNL 116[3] notes that a minimum acceptable strength at the time of stripping should be established by the precast concrete plant engineer or the engineer of record and should be stated on the drawings. Stripping or prestress transfer strengths are suggested to be a minimum of 2000 psi (13,790 kPa) for nonprestressed units and 3000 psi (20,690 kPa) for prestressed units. Higher concrete strengths at stripping are normally dictated by comparing the stresses in the concrete during stripping with the specified allowable stresses.

7. Indicate most typical parameters (minimum embedment, rusted or bright strand, and configurations) used for lifting loops. (25)

Commentary Most respondents (68%) use ½ in. (13 mm) diameter strand for lifting loops with a minimum embedment of 24 to 25 in. (610 to 635 mm), which corresponds



Strand lifting-loop configurations.

Typical design parameters for ½ in. and 0.6 in. diameter strand loops

Strand diameter		0.5 in. (68%), %	0.6 in. (29%), %
Minimum embedment	Member depth	0	67
	24 to 25 in.	64	0
	36 in.	0	33
	10 in.	9	0
	40 in.	9	0
	46 in.	9	0
Surface condition	Bright	46	75
	Rusted	31	0
	Either	23	25
Parallel or tie	Parallel	75*	80*
	Tie	17	0
	Both	17	20
Straight, bent, or broom	Straight	54	40
	Bent	46	80
	Broom	8	20

Note: 1 in. = 25.4 mm.
*44% of the respondents for parallel loops of ½ in. strand and 25% of the respondents for parallel loops of 0.6 in. strand indicated they use an inverted V shape (shown above) instead of a primarily parallel shape.

to the *PCI Design Handbook*[2] recommendations. Some respondents indicated that they typically use an embedment depth that is 2 or 4 in. (51 or 102 mm) less than the member depth, even if that level of embedment is not technically required for adequate development length. One respondent indicated use of 9/16 in. (14 mm) diameter strand for typical lifting loops.

Moustafa[5] test results for ½ in. (13 mm) diameter strand lifting loops suggest development lengths of 36, 24, and 24 in. (914, 610, and 610 mm) for straight, broom, and 90-degree bend configurations, respectively, for bright strand in 3000 psi (20,690 kPa) concrete. These tests were all performed using the tied configuration. Kuchma et al.[7] compared tied and parallel configurations for deck beams less than 24 in. deep and found that the parallel legs exhibited higher capacities than the tied legs.

Most producers use a parallel configuration instead of a tie, but many indicated that they use an inverted V shape more often than a primarily parallel shape. The end conditions of the loop are typically straight or bent, and broom is rarely used. For 0.6 in. (15 mm) diameter strand, which requires longer embedment, bent ends are more typical. For ½ in. (13 mm) diameter strand, straight ends are slightly more typical.

Beyond the prescriptive recommendations in the *PCI Design Handbook*,[2] other PCI documents are more qualitative and performance based in their guidance. The *PCI Bridge Design Manual* (MNL 133)[8] states, "Strand embedment must be of sufficient length to avoid bond failure. Tails can be added to the ends of the loops to increase embedment. The surrounding concrete should be adequately reinforced to prevent splitting and loss of bond."

8. What, if any, measures are taken to protect strand lifting loops from corrosion? (19)

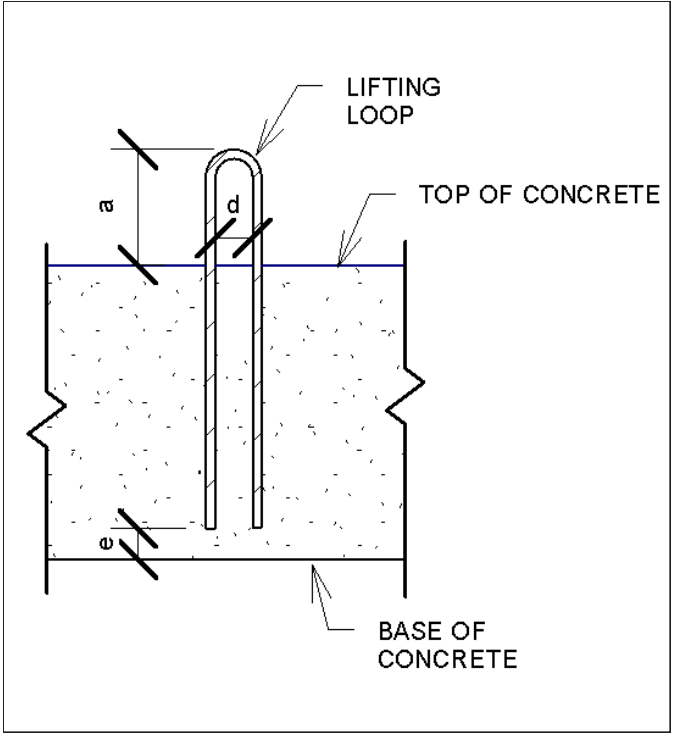
A variety of mitigation measures were reported, including storing indoors, dipping in rust-resistant paint, and spraying with epoxy paint if long-term storage is planned and zinc primer if stored during winter months. However, most respondents (74%) reported that no anticorrosion measures are taken. Many noted that they use the strand before it experiences severe corrosion and otherwise do not use that strand.

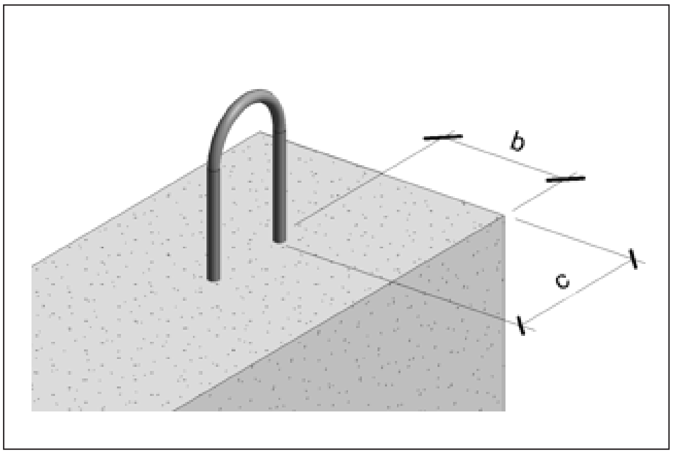
9. What criteria do you use when evaluating the condition of the strand surface, such as bright or rusted? (12)

- visual inspection: 50%
- surface rust acceptable, but no pitting: 25%
- pencil eraser test for rust: 17%
- only use new strands without rust: 17%

Commentary Significant rust (pitting) can compromise the breaking strength of the strand; however, lightly rusted strand can actually be helpful in reducing the required development length of the strand, as shown by Moustafa[5] testing. MNL 116[3] provides a list of potential corrosion-protection methods that also protect against embrittlement. Such methods include shop primer paint, zinc-rich paint, zinc metalizing, cadmium plating, hot-dip galvanizing, and epoxy coating.

10. For the ½ in. (13 mm) diameter loop shown in Fig. 4, please provide typical and/or maximum/minimum dimensions based on your company's standard practices. (24)





Schematic of lifting-loop dimensions and edge distances; Fig. 4 from the survey.
Note: *a* = typical vertical distance from top of concrete to top of loop; *b* = minimum edge distance from loop to edge of concrete; *c* = minimum end distance from outward leg of loop to end of concrete; *d* = typical bend diameter; *e* = minimum cover from bottom of concrete to end of loop.

11. For I-girders, what is the minimum clear cover to lifting loops in a thin web? (21)

- 1 to 1.5 in. (25 to 38 mm): 16%
- 2 to 2.5 in. (51 to 64 mm): 26%

Typical dimensional parameters for ½ in. diameter strand loops

Dimensional parameter, in.		Survey results, %
Typical vertical distance from top of concrete to top of loop *a*	3 to 5	21
	6 to 8	38
	10 to 12	38
	18	4
Minimum edge distance from loop to edge of concrete *b*	2 to 4	26
	6 to 9	58
	10 to 12	16
Maximum location tolerance limit for dimension *b*	¼ to ½	28
	1	50
	2	11
	3	11
Minimum end distance from outward leg of loop to end of concrete *c*	9 to 12	29
	15 to 18	33
	20 to 24	33
	48	5
Maximum location tolerance limit for dimension *c*	¼	11
	2	22
	3	11
	6	50
	12	6
Typical bend diameter *d*	1 to 2	10
	3	25
	4	30
	6	35
Minimum cover from bottom of concrete to end of loop *e*	2	19
	3	52
	4	10
	6	14
	8	5

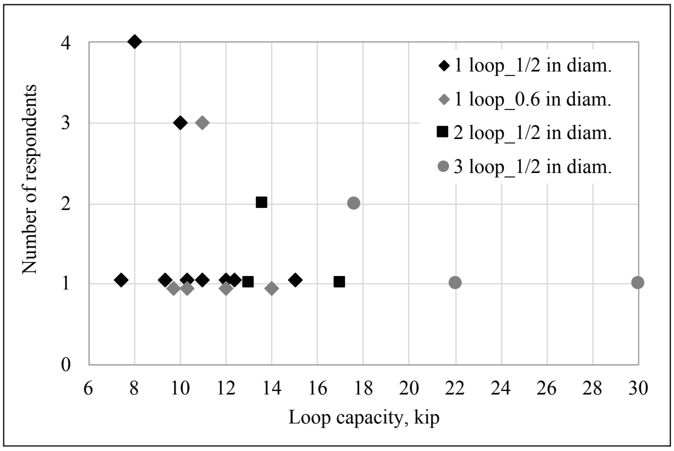
Note: 1 in. = 25.4 mm.

- 3 to 4 in. (76 to 102 mm): 26%
- Not applicable: 32%

Commentary Placement of lifting loops is an important consideration that can significantly influence safe lifting practices. Edge distance can affect failure modes, resulting in side-face blowout and other concrete breakout modes that might not have been considered. Kuchma et al.[7] studied rectangular precast concrete bridge beams (depths less than 24 in. [610 mm]) and found that loops should be placed at least 6 in. (152 mm) from the side edge of the deck with a tolerance of ±1 in. (25 mm) due to significant strength reductions at 4 in. (102 mm) of edge distance. The specimens exhibited triangle wedge cracks at the surface and edge of the concrete, ultimately resulting in breakout of the concrete wedge. This 6 in. edge distance recommendation corresponds with the survey results: 74% of respondents typically use at least a 6 in. edge distance, and 53% use a 1 in. maximum location tolerance limit.

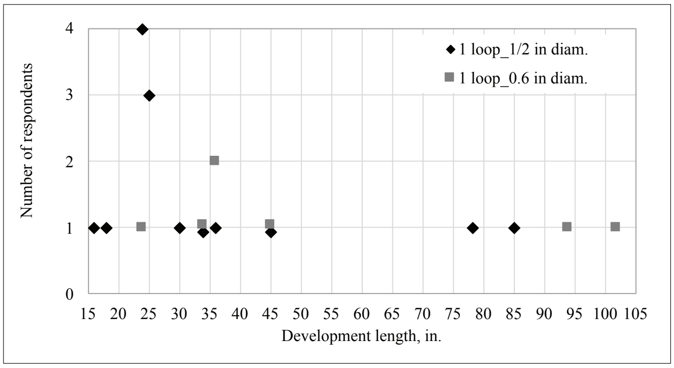
The survey results showed that the most common height of the loop measured from the top of the concrete was 6 to 8 in. (152 to 203 mm) and the minimum distance from the end of the member varied between 9 and 24 in. (230 and 610 mm) with a location tolerance limit of 6 in. The most typical bend diameter for the strand was 6 in., and the minimum cover from the end of the loop to the bottom of concrete was 3 in. (76 mm).

12. For each strand diameter listed below, please indicate the safe lifting-loop capacity that is presumed based on company standard for a vertical lift. (15)



Loop capacity versus number of respondents for ½ in. and 0.6 in. diameter strands in one-, two-, and three-loop bundles. Note: The survey also listed ⅜ in. and 7⁄16 in. diameter strands, but no respondents indicated typical use of these strand types as lifting loops. For 0.6 in. diameter strand, one respondent indicated using 17 kip for two loops, one indicated using 22 kip for three loops, and one indicated 60 kip for three loops. 1 in. = 25.4 mm; 1 kip = 4.448 kN.

13. For each strand diameter listed below, please indicate the safe development length that is presumed based on company standard for a vertical lift with a concrete strength of 3500 psi (24,130 kPa). (17)



Strand development length versus number of respondents for ½ in. and 0.6 in. diameter strands. Note: 1 in. = 25.4 mm.

Commentary The most common strengths and embedments reported in the survey for ½ in. (13 mm) diameter strand were 8 kip (35.6 kN) and 24 to 25 in. (610 to 635 mm), respectively, which are generally in accordance with the seventh edition *PCI Design Handbook*.[2] For multiple loops, strengths were primarily determined based on the multipliers provided in the handbook. With a lack of recommendation in the *PCI Design Handbook* for 0.6 in. (15 mm) diameter strand lifting loops, producers rely on previous practice to determine capacities and development lengths.

There is some significant variability in the lengths presented in the figure "Strand Development Length Versus Number of Respondents for ½ in. and 0.6 in. Diameter Strands." It is presumed that there was confusion between embedment length and development length. The question was intended to determine the presumed embedment length required to prevent pull-out failure from occurring; the large development lengths reported are presumably the development lengths used when the strand is pretensioned, not for the proposed application as a lifting loop.

14. How are the loops temporarily held in place while concrete is placed? (25)

All respondents except one indicated that the loops are tied to reinforcing bar using wire ties. The exception uses wood blocking and sometimes steel brackets to hold the loops in place.

15. Are lifts on lifting loops typically vertical or inclined? (24)

- vertical: 75%
- inclined: 25%

16. What is the maximum permissible incline angle (measured from the horizontal)? (4)

- 60 degrees: 50%
- 45 degrees: 25%
- 30 degrees: 25%

Commentary The angle of the lift affects the capacity of the lifting loop. MNL 127[4] notes that lift angles are not usually less than 60 to 70 degrees from the horizontal and does not recommend angles less than 30 degrees from the horizontal. MNL 116[3] puts stricter limits on the lifting angle, stating that the angle should not be less than 45 degrees from the horizontal unless specifically shown on the shop drawings. Alternative rigging strategies should be considered if the pull angle becomes too shallow. Kuchma et al.[7] compared angles of pull at 45 and 60 degrees from the horizontal. Their results show an increase in strength as the angle becomes closer to the vertical.

17. What attachment hardware is typically used for lifting the loops? (24)

- hooks: 75%
- shackles: 54%
- other: 4%

18. What is the standard pin diameter typically used for the attachment hardware? (15)

- 1 to 1½ in. (25 to 38 mm): 20%
- 2 to 2¾ in. (51 to 70 mm): 33%
- 3 in. (76 mm): 13%
- 6 in. (152 mm): 7%
- not applicable: 27%

Commentary The diameter of the lifting hardware can influence the breaking strength of the lifting-loop strand. "Small diameter shackle pins or hooks, when used through strand lift loops, can significantly decrease the capacity of the loop" (MNL 133[8]). In addition, "the diameter shall be such that localized failure will not occur by bearing on the lifting device" (MNL 116[3]).

The *PCI Design Handbook*[2] indicates that the diameter of the hook/hardware should be at least four times the diameter of the strand being used; this is to prevent these localized failures from occurring.

Moustafa[5] compared the breaking strength of the loops with 1, 2, and 3 in. (25, 51, and 76 mm) pin diameters and found that the capacity of the ½ in. (13 mm) diameter strand loop increased from approximately 65 kip (289 kN) at 1 in. to 75 kip (334 kN) at 3 in. Kuchma et al.[7] found that hooks created sharp bends in the strand that led to pinching and ultimately reduced strength of the strand when pulled at an angle of 30 degrees from the vertical.

19. Do you incorporate any supplemental reinforcement in the beam to increase loop capacity? (23)

Twenty-two out of twenty-three respondents indicated that they do not design supplemental reinforcement for the lifting loop. The lone respondent who said "yes" indicated that they use ties around parallel legs of each lifting eye for field lift loops.

Use of multiple loops in one location

20. How many strand loops are typically used in multiple loop bundles? What is the maximum number of strand loops that you use in each bundle? (20)

Typical and maximum number of loops used in multiple loop bundles

Number of loops	Typical, %	Maximum, %
2	60	5
3	40	35
4	15	35
5	5	15
6	5	10

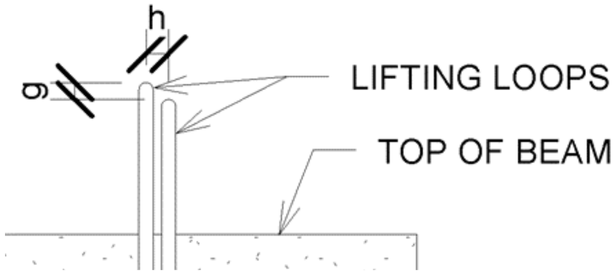
21. Do you use a conduit or pipe around the strand? (21)

- yes: 86%
- no: 14%

22. What procedure is used to ensure loads are evenly distributed between loops? (21)

- conduit: 71%
- precision in loop layout: 29%
- pipe: 19%
- other: 10%

23. For the two loops shown in Fig. 7, please provide the maximum permissible vertical offset distance *g* and the maximum permissible horizontal offset distance *h*. (17)



Schematic of two loops in multiple loop bundle; Fig. 7 from the survey. Note: g = vertical offset distance; h = horizontal offset distance.

Maximum permissible offset distances in multiple loop bundles		
Maximum permissible offset	**Vertical offset distance *g*, %**	**Horizontal offset distance *h*, %**
0 in./use conduit	64	55
¼ to ½ in.	27	36
2 in.*	9	0
4 in.*	0	9

Note: 1 in. = 25.4 mm.

*The 2 and 4 in. responses were provided by the same respondent, and it is presumed that the respondent misunderstood the question.

24. If a loop is found to be outside of the maximum permissible vertical or horizontal distance provided in question 23, what methods do you employ to ensure that all loops are evenly loaded during lifting? (9)

A number of unique responses were provided, including the following:

- remove and install new device
- cushion high strand with another piece of strand
- shim the shackle pin on the higher loops
- evaluate whether all strands are actually needed and find alternate lifting if necessary
- rolling block equalizer
- use a pipe jig with a bolted cover plate to prevent vertical offsets from occurring
- use tight conduit to prevent this from occurring
- individual hookup to parallel rigging

25. Do you apply a reduction factor to the pull-out capacity of multiple strand loops? (19)

- yes: 58%
- no: 42%

Of those who replied "yes," six respondents indicated that they use factors of 0.85 for double and 0.73 for triple loops (per *PCI Design Handbook* recommendations). One indicated that they use factors of 1 for double, 0.866 for triple, and 0.91 for quadruple loops; it is presumed that these values were incorrectly reported because the reduction factor for four loops should not be greater than the factor for three loops.

Commentary Precision must be used in the fabrication of products with multiple loops in one location. Failure to ensure equal loading among all loops could result in failure of one of the loops and, ultimately, progressive failure of the remaining loops. MNL 127[4] states, "The erector should verify that (1) loops are of equal projection when used as a pair or in groups so that the unit will hang level and plumb, (2) bundled or multiple strand loops are positioned so that they equally share the load, and (3) individual wires are not broken or damaged." Similarly, MNL-116[3] states, "To avoid overstressing one lifting loop when using multiple loops, care shall be taken in the fabrication to ensure that all strands are similarly bent and positioned to ensure even distribution of load between loops." This is further emphasized in MNL 116.[3] "Multiple component lifting devices shall be kept matched to avoid non-compatible usage. When grouped in multiples, lifting loops shall be aligned for equal lifting. The projection of the lifting loops shall be maintained within a tolerance consistent with the adjustment capabilities of the lifting hardware."

MNL 133[8] states that schedule 40 or 80 bent pipe can be used to ensure even loading of a strand bundle. Similarly, the *PCI Design Handbook*[2] suggests that thin-wall conduit over the loops in the region of the bend can be used. It also suggests that "when using double- or triple-strand loops, the embedded ends should be spread apart so that adequate concrete consolidation around the ends is achieved." The handbook provides safe working load multipliers for using double or triple loops; these values are 1.7 and 2.2, respectively. Kuchma et al.[7] tests validated these suggested strength multipliers. They also found that strands must be the same length, otherwise they perform as only one loop.

Conclusion

Twenty-three out of twenty-four respondents indicated "no" when asked if their company has experienced any major problems associated with strand lifting loops. The sole positive response indicated fracture as the observed failure mode. The data collected in this paper will be used in conjunction with the limited research permitted by this fellowship to develop recommendations for the safe use of strand lifting loops to the extent possible.

Acknowledgments

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Abstract

Cutoff or waste prestressing strands (ASTM A416/A416M) are often used to lift precast concrete elements at the casting yard and project site. These pieces of strands are mechanically bent into loops and cast into the concrete at the necessary embedment and projection above the surface to ensure safe lifting of the element. With limited guidance provided in codes and standards, precast concrete producers have primarily relied on previous practice and engineering judgment to design and detail safe lifting loops. A survey was administered in April 2019 as part of a Dennis R. Mertz Fellowship project to understand the typical strand lifting-loop practices among PCI-certified precast concrete producers. This paper presents a summary of the raw survey results based on 35 respondents. The survey shows general conformance to the recommendations of the *PCI Design Handbook*: *Precast and Prestressed Concrete* for ½ in. (13 mm) diameter strand loops but variability in many lifting-loop design parameters.

Keywords

Anchorage, current practice, industry survey, lifting loop, prestressing strand.

Reader comments

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