Discussion of "Monitoring Secondary Moments of Continuous Unbonded Post-Tensioned Concrete Beams," published in PTI JOURNAL, December 2018, pp. 5-16

By
Kyungmin Kim and Thomas H.-K. Kang

Authorized reprint from: July 2019 issue of the PTI Journal

Discussion of "*Monitoring Secondary Moments of Continuous Unbonded Post-Tensioned Concrete Beams*," Kyungmin Kim and Thomas H.-K. Kang, published in *PTI JOURNAL*, December 2018, pp. 5-16

BY KENNETH B. BONDY

This paper conflicts with the entire history of American post-tensioned concrete building construction, including field experience, research, and engineering logic. Surely if secondary moments were roughly 10 times larger than normally calculated (as the authors allege), that would have been noticed in the last 60 years of indeterminate post-tensioned beam behavior. It never was. Secondary moments were first required to be included in strength calculations by ACI 318-77. Since then, over 40 years ago, they have been calculated for many thousands of indeterminate post-tensioned beams using the authors' Eq. (10), which is fully detailed and explained in the PTI Post-Tensioning Manual.[1] These existing beams would obviously have exhibited serious deficiencies if the actual secondary moments were in fact 10 times larger than predicted by Eq. (10). Because secondary moments are typically additive to positive (field) moments caused by external dead and live loads, there would be severe cracking problems, deflection problems, and flexural failures in virtually every indeterminate post-tensioned beam ever built. If the authors were correct in their allegations about secondary moments, joint moments in virtually all multi-span post-tensioned beams would reverse and negative moments would no longer exist. In fact, of course, no such pervasive problems related to secondary moments have ever been observed. Considering these facts, one must trust the decades of behavioral observations and not the bizarre allegations of the authors.

As an example, consider a very typical 14 in. (360 mm) wide x 36 in. (910 mm) deep parking structure beam designed in accordance with the International Building Code, with 5000 psi (34 MPa) normalweight concrete, two equal 65 ft (20 m) spans, spaced at 20 ft (6.1 m) on center with a 5 in. (130 mm) slab between beams, and 18 in. (460 mm) square columns 12 ft (3.7 m) long above and below. The final design of the beam requires eleven 1/2 in. (13 mm) diameter 270 ksi (1860 MPa) unbonded tendons with a parabolic drape and high- and low-point CGS dimensions of 4 in. (103 mm) each. The factored dead and live load moments (1.2DL and 1.6LL) acting at the face of the interior column are –955 and –526 ft-kip

PTI JOURNAL, V. 15, No. 1, July 2019. Received and reviewed under Institute journal publication policies. Pertinent discussion will be published in the next issue of *PTI JOURNAL* if received within 3 months of the publication.

(–1290 and –710 kN-m), respectively, and the unfactored secondary moment calculated by Eq. (10) is +309 ft-kip (+420 kN-m). This results in a factored design moment at the center support of –955 – 526 + 309 = –1172 ft-kip (–1580 kN-m). If the secondary moment were in fact 10 times larger, as the authors claim, the resulting moment at the center support would be –955 – 526 + 3090 or a POSITIVE +1609 ft-kip (+2180 kN-m)—much larger in magnitude than the normally calculated factored design moment of –1172 ft-kip (–1580 kN-m) and in the opposite direction. For this beam, the conventional design at the center support would require four No. 9 bars—fully developed, at the top of the beam, along with the 11 tendons—to resist the design negative moment. No compression reinforcement is required at the bottom of the beam, so the bottom bars would consist of just two No. 8 bars, which are required to resist the positive moment at midspan. The two No. 8 bottom bars would typically be lapped over the support. Obviously, the beam would fail in flexure in positive moment at the support, because the bottom beam reinforcement is grossly inadequate. The fact that this behavior has never been observed raises serious doubts about the accuracy and credibility of the authors' results and conclusions.

The authors point out that few researchers have measured secondary effects in their testing. However, one highly credible researcher, Alan Mattock, did in fact measure them in his classic work on indeterminate post-tensioned beams in 1969.[2] In this work, the researchers measured the center reaction in three two-span beams caused by dead load and prestress forces (including significant secondary effects) and found that the measured value ranged between 1.006 and 1.02% of the calculated value (using the normal method for calculating secondary moments—the authors' Eq. (10)). That is strikingly good agreement and differs wildly from the results presented by the authors of this paper. So the authors' conclusion that their measured secondary moments were 10 times larger than the calculated values is seriously at odds with not just the observable behavior of existing post-tensioned beams, but at least one highly respected and influential research publication.

This discusser performed independent calculations for secondary moments in the test beam 4L, using commercially available software which has been calculating secondary moments in more than 700 structural design offices worldwide since 1983. These calculations indicate a secondary moment at the interior support of 17 ft-kip (22.9 kN-m) approximately 57% higher than that calculated by the authors in Table 3 (11 ft-kip [14.6 kN-m]) and still only one-sixth of their "measured" value for that beam (103 ft-kip [139.6 kN-m]). In these calculations, a compound-parabola tendon profile was used with four parabolas in each span, two concave downward at the supports and two concave upward between them, with inflection points at one-tenth of the beam span from each support (the "Type 3" tendon profile in the commercial software). This was done because the authors seem to be critical of the commonly used single-parabola "ω-shaped profile with kink," as they describe it in the second paragraph under "OBSERVATION AND DISCUSSION". Using this tendon profile slightly reduced the calculated values of the secondary effects from those calculated with a single-parabola "kinked" profile. This means that both the authors' calculated and measured values of secondary moments, as presented in Table 3, are highly suspect.

Two other less significant points should be mentioned. In "SUMMARY AND CONCLUSIONS," Item No. 2, the authors suggest, without evidence, that secondary moments are different if the tendons are bonded or unbonded (presumably with all else equal). To the discusser's knowledge, no one in the history of prestressed concrete has ever suggested this. In a bonded tendon, the bond is obviously applied after the tendons are stressed and the secondary moments have already been generated. While it is true that secondary moments are a function of tendon force, and the tendon force varies differently with loading for bonded and unbonded tendons, this is a minor effect and has been historically ignored in practice and not recognized by Codes. Finally, the first sentence under "STATICS ANALYSIS" is puzzling. If the magnitudes of the applied loads are known, as the authors acknowledge they are, the three reactions (L, RE, and RW) are easily calculated with standard indeterminate methods. Perhaps the authors meant something else here, but as it reads, it is grossly incorrect.

Finally, the first sentence under "STATICS ANALYSIS" is puzzling. If the magnitudes of the applied loads are known, as the authors acknowledge they are, the three reactions (L, R_E, and R_W) are easily calculated with standard indeterminate methods. Perhaps the authors meant something else here, but as it reads, it is grossly incorrect.

REFERENCES

1. Post-Tensioning Manual, sixth edition, Post-Tensioning Institute, Farmington Hills, MI, 2006.

2. Yamazaki, J.; Kattula, B. T.; and Mattock, A. H., "A Comparison of the Behavior of Post-Tensioned Beams with and without Bond," Structures Mechanics Report SM69-3, Department of Civil Engineering, University of Washington, Seattle, WA, Dec. 1969.

Closure to Discussion by Kenneth B. Bondy concering “*Monitoring Secondary Moments of Continuous Unbonded Post-Tensioned Concrete Beams,*” Kyungmin Kim and Thomas H.-K. Kang, *PTI Journal*, December 2018, pp. 5-16

BY KYUNGMIN KIM AND THOMAS H.-K. KANG
WITH CONTRIBUTION FROM HYEONGYEOP SHIN AND BYEONGUK AHN, SEOUL NATIONAL UNIVERSITY FOR INDEPENDENT DETAILED ANALYTICAL CALCULATIONS

First, the authors express gratitude for the discusser’s interest in the paper, whom the authors recognize for his achievements in post-tensioning. The second author is particularly proud of being a recipient of the Kenneth B. Bondy Award for Most Meritorious Technical Paper. The authors’ responses to comments are as follows.

The third conclusion reached in the original paper was that “the measured total actuator load exceeded the plastic capacity of the whole member calculated through plastic analysis theory, where nominal moment strengths were assumed to be reached at all critical sections,” even though assessed secondary moments were 10 times larger than normally calculated, and “unlike the existing postulation, the bending resistance at the interior support location seemed to be achieved from a combination of two different mechanisms: by internal beam moment resistance and by hold-down force induced by the post-tensioning.” Thus, “conventional sectional analysis does not seem to be appropriate for indeterminate unbonded PT structures.”

In the authors’ paper, recently accepted for publication in *ACI Structural Journal* (Kim and Kang 2019), this was confirmed as shown in Fig. D1 and D2. In addition, four similar specimens (D3H, D3L, D4H, and D4L) with 2400 MPa (350 ksi) tendons were also investigated in the ACI paper.

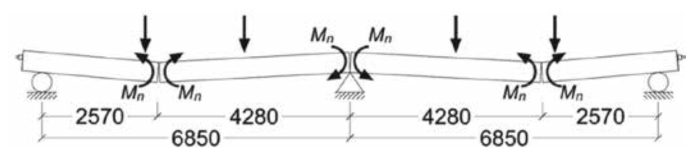

Fig. D1—Plastic hinge model (adapted from Kim and Kang 2019). (Note: Units in mm; 1 mm = 0.039 in.)

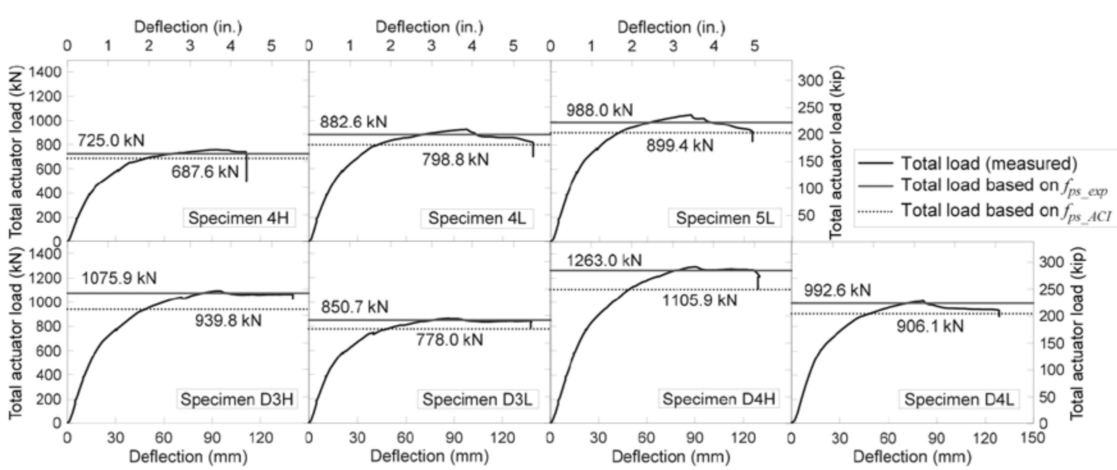

Fig. D2—Load-deflection curves (adapted from Kim and Kang 2019).

PTI JOURNAL, V. 15, No. 1, July 2019. Received and reviewed under Institute journal publication policies. Pertinent discussion will be published in the next issue of *PTI JOURNAL* if received within 3 months of the publication.

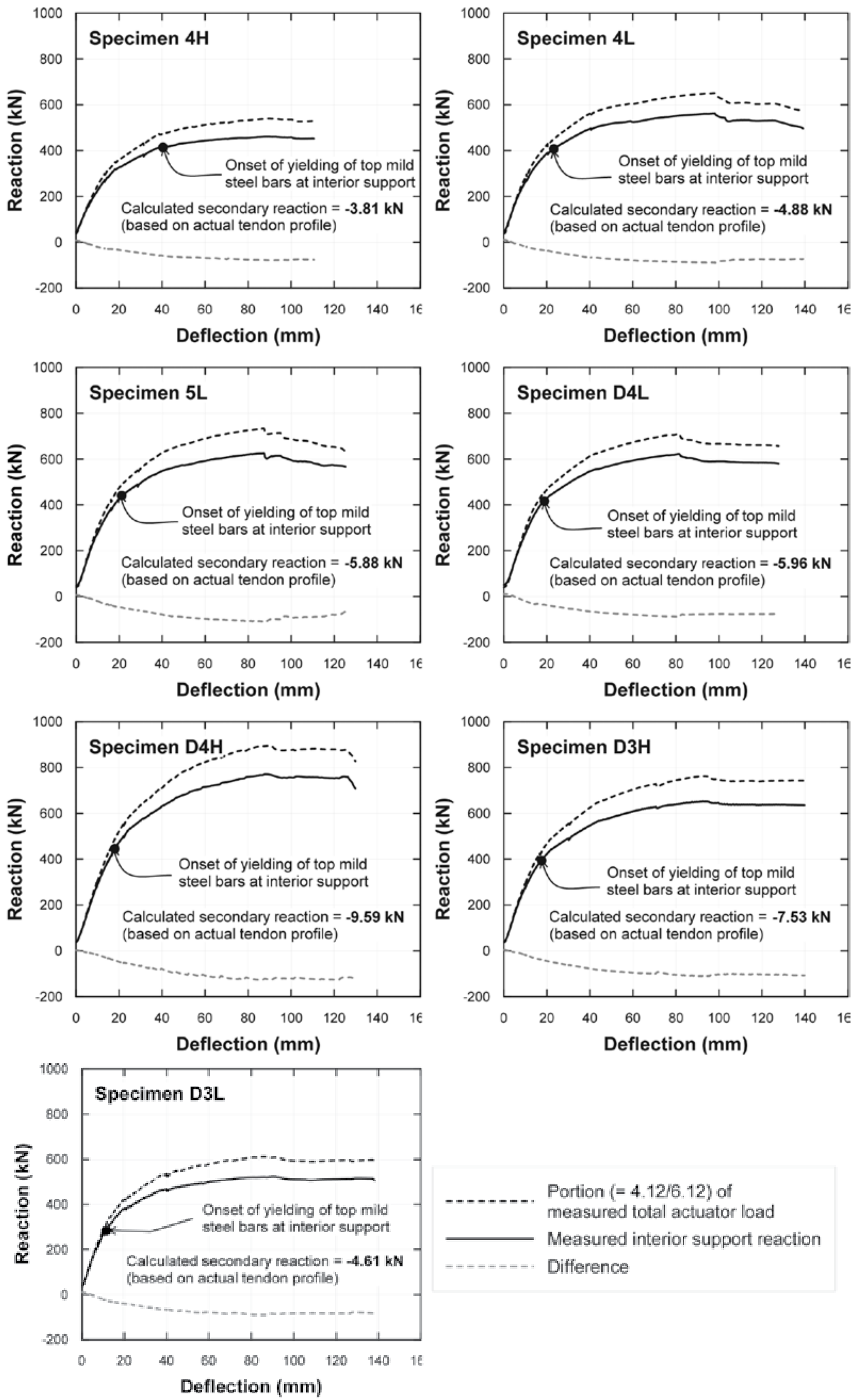

Fig. D3—Support reaction data from all specimens. (Note: 1 kN = 0.225 kip.)

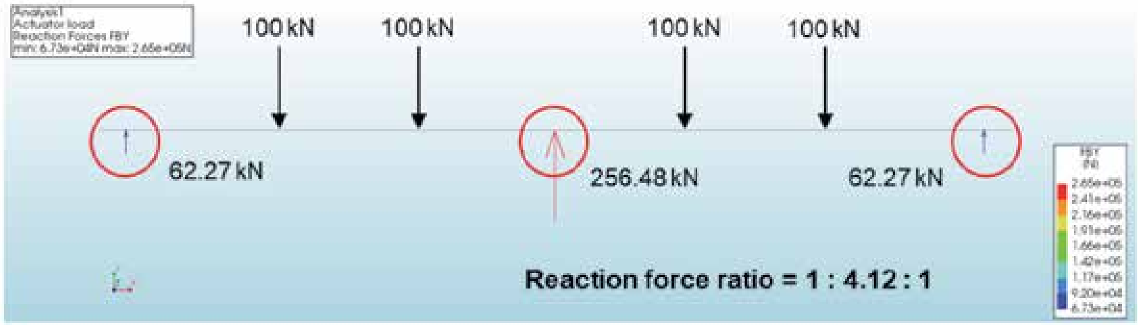

Fig. D4—Elastic analysis of indeterminate beam. (Note: 1 kN = 0.225 kip.)

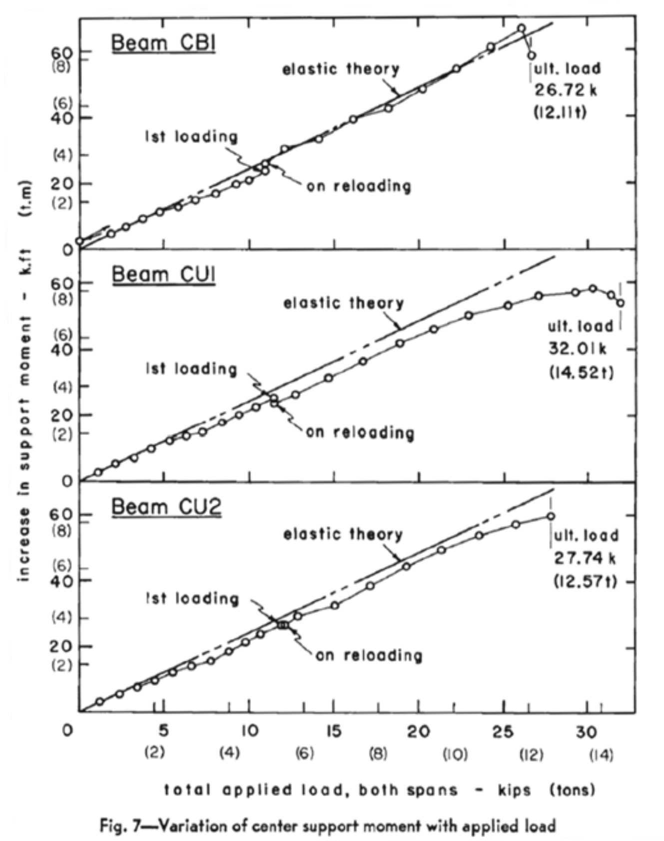

Fig. D5—Support moment (adapted from Mattock et al. 1971a).

Figure 10 of the original paper is re-plotted using the original data in Fig. D3, along with the data of the other specimens D3H, D3L, D4H, and D4L. The load cell installed at the interior support was checked using a universal testing machine before and after the beam testing, so the interior support reaction histories are correct for all seven specimens. The black dashed line is obtained from the total applied load multiplied by (4.12/6.12). This ratio is from the elastic analysis as shown in Fig. D4, and is expected to be the same until plastic moment is reached. The difference (hold-down force) is also plotted. Under internal bending moment resistance mechanism, the secondary reaction force (hold-down force) is unexplainable.

The authors would like to stress that the secondary reaction was very small with self-weight only before the external loading was applied, which is consistent with the calculated secondary reaction (–9.59 to –3.81 kN [–2.16 to –0.86 kip]). However, secondary reaction appeared to increase significantly as the loading increased.

Within the figures, negative value means downward direction (pulling reaction).

In regard to Mattock's research (Mattock et al. 1971a, b), the authors do not have the full University of Washington report by Yamazaki, Kattula, and Mattock. As such, it is unclear to the authors as to how center support moment was obtained according to Mattock et al.'s ACI papers (1971a, b) and depicted in Fig. 7 therein (refer to Fig. D5 herein). The authors believe that this was not measured center support "reaction," but center support moment derived based on other information, because no center reaction histories were provided.

As to analytical secondary moments in the original paper, calculations based on the conventional indirect method were checked and rechecked with detailed procedures reproduced in the Appendix (https://www.post-tensioning.org/publications/ptijournal.aspx).

REFERENCES

Kim, K., and Kang, T. H.-K., 2019, "Experiments on Continuous Unbonded Post-Tensioned Beams with 2400 MPa Strands," *ACI Structural Journal*, V. 116, 2019, accepted for publication.

Mattock, A. H.; Yamazaki, J.; and Kattula, B. T., 1971a, "Comparative Study of Prestressed Concrete Beams, with and without Bond," *ACI Structural Journal*, V. 68, No. 2, Feb. 1971, pp. 116-125.

Mattock, A. H.; Yamazaki, J.; and Kattula, B. T., 1971b, "Part 2 – Comparative Study of Prestressed Concrete Beams, with and without Bond," Supplement to *ACI Structural Journal*, V. 68, No. 2, Feb. 1971.