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Bending Properties of Parallel Chord Truss with Steel-Web Members

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ABSTRACT

A truss is a structure in which the members are connected and arranged such that they are primarily subjected to axial loading. A truss has the advantage that it can be used for a longer span because the structure distributes the applied force to its members well, and the load is transmitted only in the axial direction of the members. Trusses manufactured using timber have more advantages than those made of other materials. In this study, the properties of parallel chord trusses composed of timber chord and steel-web members were evaluated. We constructed truss specimens with various lengths by using upper and lower chords of 2 × 4 inch spruce-pine-fir lumber and steel-web members manufactured by S and P companies. The specimens were tested in accordance with KS F 2150. The test results showed that the load at the deflection limit and the deflection limit itself increased from L/180 to L/360 regardless of the length of the specimens. For specimens of the same length, the load at the deflection limit increased as the height of the parallel timber chord truss specimens increased from 200 to 300 mm. Successive installations of the steel-web members (SST) showed almost 2 times the load at each deflection limit compared to that of SAT specimens (alternate installation of the steel-web members). When comparing the three load–deflection limits in terms of the manufacturer of the steel-web members, the load at each deflection limit for SST specimens was higher than that for PST specimens.

Keywords: truss structure, bending strength, parallel chord truss, steel-web member, deflection limit

1. INTRODUCTION

Many studies have been conducted on shear walls in timber construction (Jung *et al*., 2020; Lee and Jang, 2023). However, studies on roof and floor systems are not as numerous as those on shear walls. In timber construction, the deflection and creep of the floor and roof systems as well as the shear wall are important. For joists used in floor and roof systems, 2″ × 6″ or larger structural lumber should be used. When using structural lumber as a joist, there are restrictions on long spans. Owing to these problems, engineered wood such as glulam or CLT is mainly used and studied instead of structural lumber over long spans (Choi *et al*., 2020; Fujimoto *et al*., 2021; Yang *et al*., 2021). Galih *et al*. (2020) studied the mechanical properties of tropical hybrid cross-laminated timber using a bamboo-laminated board as the core layer. Park *et al*. (2020a) evaluated the bending creep properties of cross-laminated wood panels composed of tropical hardwoods and domestic temperate

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wood. Park *et al*. (2020b) tested the bending creep of glulam and bolted glulam under varying relative humidity. Choi *et al*. (2021) evaluated the flexural performance of ply lam CLT according to the plywood bonding method. Hwang *et al*. (2022) monitored the moisture and dimensional behavior of a nail-laminated timber concrete slab exposed to an outdoor environment. In addition to glulam and CLT, truss is a bending member that can be used for long spans. A truss is a structure in which the members are connected and arranged such that they are primarily subjected to axial loading. A truss has the advantage that it can be used for a longer span because the structure distributes the applied force to its members well, and the load is transmitted only in their axial direction. Trusses manufactured using timber have more advantages than those made of other materials. The advantages of timber trusses include the following: 1) Timber trusses are usually more cost-effective than metal trusses; 2) Wood trusses offer excellent thermal properties, particularly compared to steel; 3) Timber trusses are more flexible and versatile than those manufactured using other materials. Owing to these advantages, numerous studies on trusses have been conducted worldwide. Šilih *et al*. (2005) designed plane timber trusses by considering joint flexibility. Komatsu *et al*. (2018) experimentally and numerically analyzed the nonlinear behavior of wooden parallel chord trusses composed of self-tapping screws. However, only a few studies have been conducted on timber trusses in South Korea. Cha (1992) studied metal and plywood gusset plate connections for light-frame wood truss tension joints. Kim *et al*. (2014) studied the strength and application of OSB gusset trusses in field assemblies.

A truss in which the chord is made of timber and web members are made of steel is easier to manufacture than a truss in which both the chord and web members consist of timber. Moreover, it has the advantages of being cheaper, lighter to lift, and faster to install. Trusses consisting of timber chords and steel-web members have also been developed in other countries. Isopescu and Gavriloaia (2015) determined the model damping ratio of a hybrid floor system composed of timber chord and metal web members. Lennon *et al*. (2010) conducted a natural fire test on three engineered timber floor systems, including a timber truss incorporating upper and lower solid-timber chord members, and a pressed steel-web member.

In this study, a parallel chord truss was manufactured using steel-web members of a domestic company, S Co., and foreign company, P Co., for roof and floor systems. The bending properties of the two parallel-chord trusses were evaluated and compared.

2. MATERIALS and METHODS

2.1. Materials

2.1.1. Timber chord members

In this study, to manufacture truss specimens, northern SPF No. 2 2 × 4 inch lumbers were used for the upper and lower chords. For all truss specimens, the upper and lower chord members were made of one piece of lumber without a lengthwise connection.

2.1.2. Steel-web members

Concerning the steel-web members, two different types of steel-web materials, produced domestically and abroad, were used to compare their performance. The shapes and dimensions of the steel-web members used in this study are shown in Fig. 1 and listed in Table 1. Fig. 1(a) depicts a steel-web member manufactured by S Co., a domestic company. Fig. 1(b) shows the steel-web manufactured by P Co., a foreign company.

2.1.3. Truss specimen

The parallel timber chord truss with steel-web (PCTSW) specimens used in this study were composed of timber chords and steel-web members, as depicted in

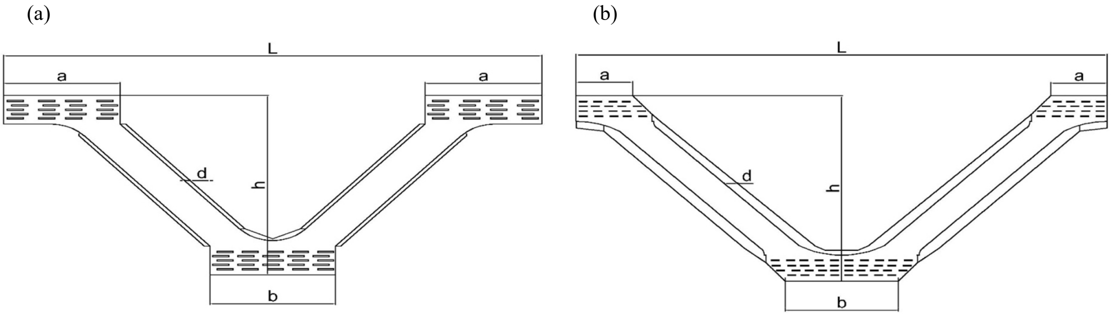

Fig. 1. Steel-web members. (a) Shape of the steel-web member manufactured by S Co., a domestic company, (b) shape of the steel-web member manufactured by P Co., a foreign company.

Table 1. Specification of the steel-web members

Steel web-member	Material	a (mm)	b (mm)	L (mm)	h (mm)	d (mm)
S Co.	Z275M280	100	135	600	200 250 300	7.34
P Co.	Z275M220	70	160	610	250 300	13

Fig. 2, and are constructed as shown in Table 2. Note from this figure that the SAT specimen was manufactured by alternate installation of the steel-web members on both sides using those produced by the S company; SST and PST specimens were manufactured by continuous installation of the steel-web members on both sides using those produced by the S and P companies, respectively.

As listed in Table 2, the SAT specimens were manufactured using domestic S Co.; these specimens featured five different lengths and three different heights. The SST specimens were manufactured using domestic S

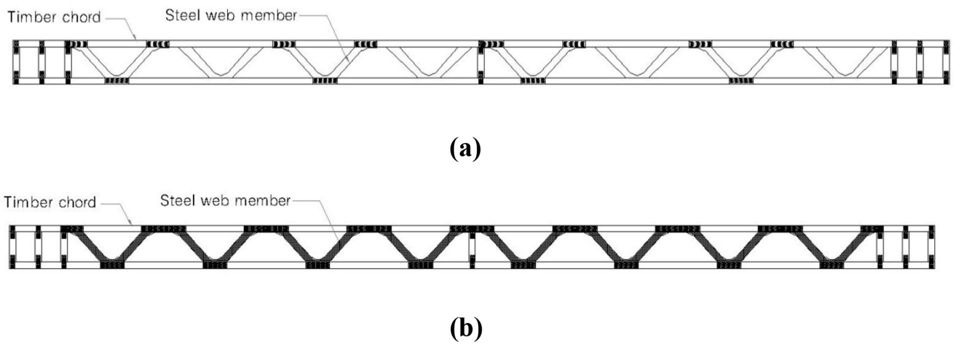

Fig. 2. PCTSW specimen. (a) SAT specimen, (b) SST and PST specimen. PCTSW: parallel timber chord truss with steel-web, SAT: S company's steel web.-Alternate installation-truss, SST: S company's steel web.-Successive installation-truss, PST: P company's steel web.-Successive installation-truss.

Table 2. Specification of the PCTSW specimens

Symbol	Web members		Height (mm)	Length (m)
	Type	Installation method		
SAT200-3.6	S. Co	Alternate	200	3.6
SAT200-4.2			200	4.2
SAT200-4.8			200	4.8
SAT250-4.2			250	4.2
SAT250-4.8			250	4.8
SAT250-5.4			250	5.4
SAT300-4.8			300	4.8
SAT300-5.4			300	5.4
SAT300-6.0			300	6.0
SST200-4.8	S. Co	Succession	200	4.8
SST250-5.4			250	5.4
SST300-6.0			300	6.0
PST250-5.4	P. Co	Succession	250	5.4
PST300-6.0			300	6.0

PCTSW: parallel timber chord truss with steel-web, SAT: S company's steel web.-Alternate installation-truss, SST: S company's steel web.-Successive installation-truss, PST: P company's steel web.-Successive installation-truss.

Co.; they presented three different heights and lengths. The PST specimens were manufactured using imported P Co. and had two different heights and lengths.

2.2. Test method

The bending tests were performed in accordance with KS F 2150 to evaluate the bending properties of the

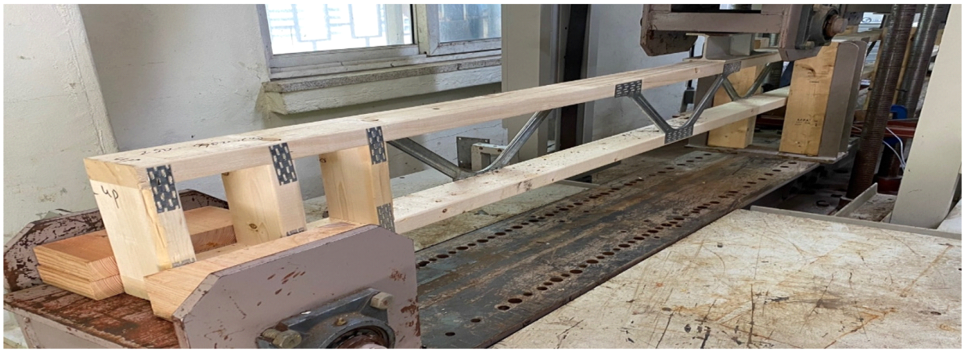

Fig. 3. Testing method to determine the bending properties of a PCTSW specimen in accordance with KS F 2150. PCTSW: parallel timber chord truss with steel-web.

truss specimens, as shown in Fig. 3 (Korea Standard Association, 2020). Note that the loading points were adjusted such that the load acted through the joints located at approximately 1/3 of the span. During the test, the deflection was measured using two linear variable differential transformers (LVDTs) attached to both sides at the middle of the specimen, and the average of two LVDTs measurements was recorded to determine the deflection of the specimen.

2.3. Calculations

Load–deflection diagrams similar to the graph shown in Fig. 4 were obtained from the bending tests of the PCTSW specimens.

In Fig. 4, the dotted lines indicate the deflection limits of 1/360, 1/240, and 1/180 of the span, which can be applied to the design according to the loading conditions. The deflection limits obtained from KDS 41 50 20 (Ministry of Land, Infrastructure and Transport, 2022a) and KDS 41 50 70 (Ministry of Land, Infrastructure and Transport, 2022b), which depend on the deflection limit under loading conditions, are listed in Table 3.

3. RESULTS and DISCUSSION

3.1. Loads at deflection limits

From the results of the bending tests for the PCTSW in this study, the loads at three deflection limits were obtained for each PCTSW specimen, as listed in Table 4.

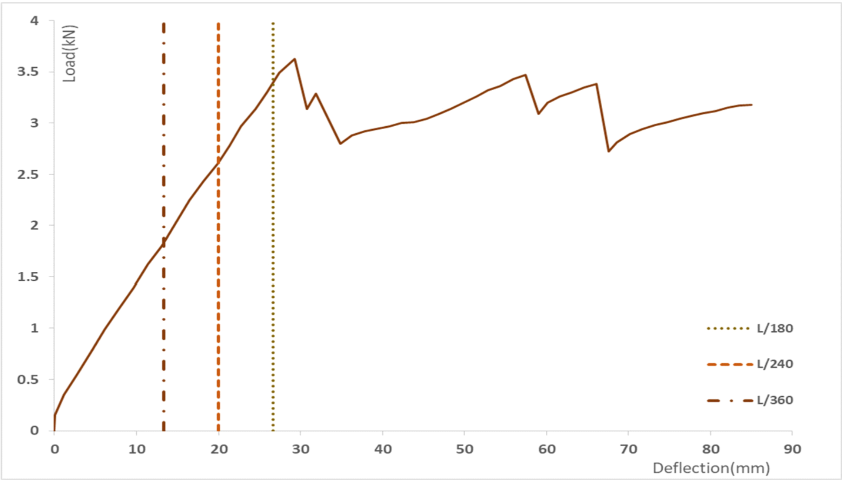

Fig. 4. Load-deformation diagram obtained from the bending test for SST200-4.8. SST: S company's steel web.-Successive installation-truss.

Table 3. Deflection limits according to the loading conditions

Building code	Use classification	Live load	Total load (Live load + dead load)
KDS 41 50 70	Roof beam Floor beam	L/240 L/360	L/180 L/240
KDS 41 50 20	Roof and floor beam	L/360	L/240

Table 4. Results of the bending test for each PCTSW

Specimen	Load at deflection limit (kN)		
	L/180	L/240	L/360
SAT200-3.6	1.41	1.16	0.83
SAT200-4.2	1.88	1.70	1.27
SAT200-4.8	1.50	1.32	0.99
SAT250-4.2	2.64	2.37	1.75
SAT250-4.8	1.90	1.61	1.21
SAT250-5.4	1.57	1.51	1.09
SAT300-4.8	1.46*	1.60	1.29
SAT300-5.4	1.62	1.50	1.15
SAT300-6.0	1.49*	1.81	1.09
SST200-4.8	3.25	2.57	1.80
SST250-5.4	3.35	2.68	1.93
SST300-6.0	2.91*	3.53	2.56
PST250-5.4	2.91	2.28	1.59
PST300-6.0	4.01	3.24	2.35

* The maximum load was reached before the deflection limit.
PCTSW: parallel timber chord truss with steel-web, SAT: S company's steel web.-Alternate installation-truss, SST: S company's steel web.-Successive installation-truss, PST: P company's steel web.-Successive installation-truss.

3.2. Failure mode

Fig. 5 shows the failure modes in the bending tests of the PCTSW specimens. In all the test specimens, failure occurred because of the shear force rather than the bending moment. The steel-web member was bent by the shear force. Subsequently, the joint between the steel-web member and upper chord failed.

3.3. Effect of the length and height of specimen

Fig. 6 depicts the change in load at three deflection limits for the SST 200 specimen featuring the same height but different lengths. This shows the effect of the length of PCTSW specimens. According to Fig. 6, the load at the deflection limit and the deflection limit itself increased from L/360 to L/180 regardless of the lengths of the specimen. Some trends were observed for all the specimens, as shown in Table 4.

Fig. 7 shows the change in load at three deflection limits for SAT specimens. Load at the deflection limit increased as the height of PCTSW specimens increased from 200 to 300 mm.

3.4. Effect of the installation method of steel-web members

Fig. 8 shows the change in load at three deflection limits for SAT and SST specimens with the same height

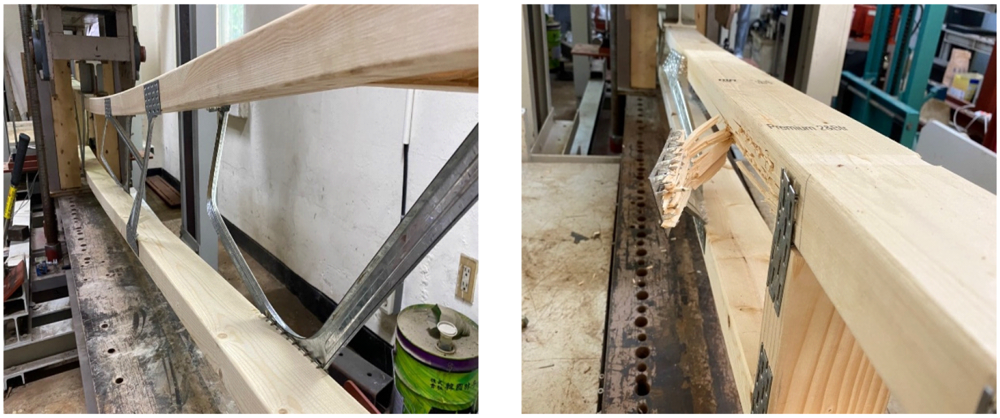

Fig. 5. Failure mode in bending test for PCTSW specimens. PCTSW: parallel timber chord truss with steel-web.

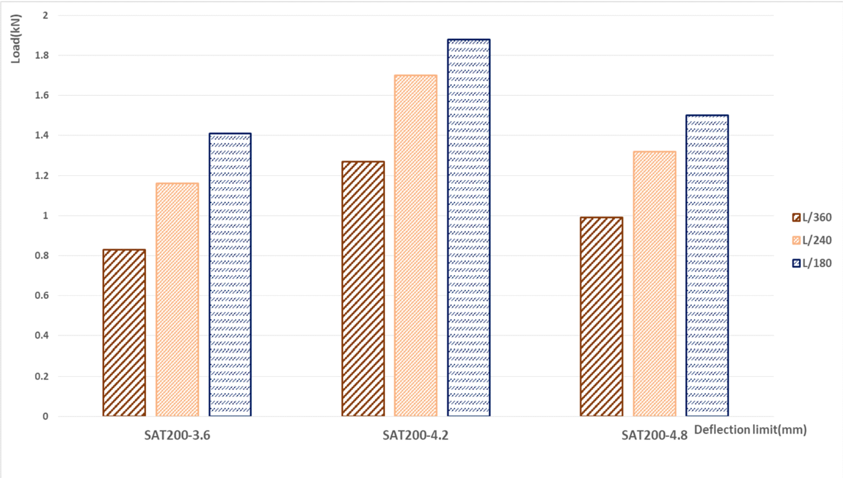

Fig. 6. Comparison of the loads at three deflection limits for SAT200 specimens. SAT: S company's steel web.-Alternate installation-truss.

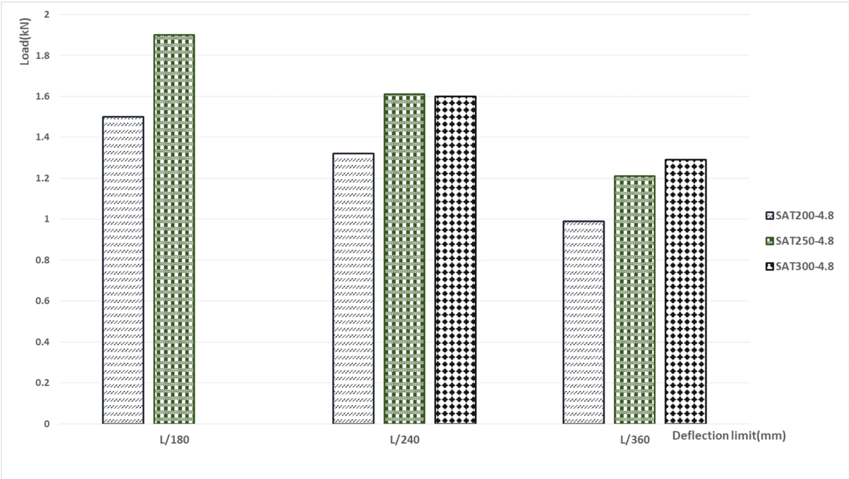

Fig. 7. Comparison of the loads at three deflection limits for SAT specimens of the same length. SAT: S company's steel web.-Alternate installation-truss.

and length. For successive installation of the steel-web members (SST), approximately 1.4–1.7 times higher load was measured at each deflection limit than that of SAT specimens (alternate installation of the steel-web members).

3.5. Effect of the type of steel-web member

The changes in load at three deflection limits for different steel-web members is shown in Fig. 9. The load at each deflection limit for SST specimens (using

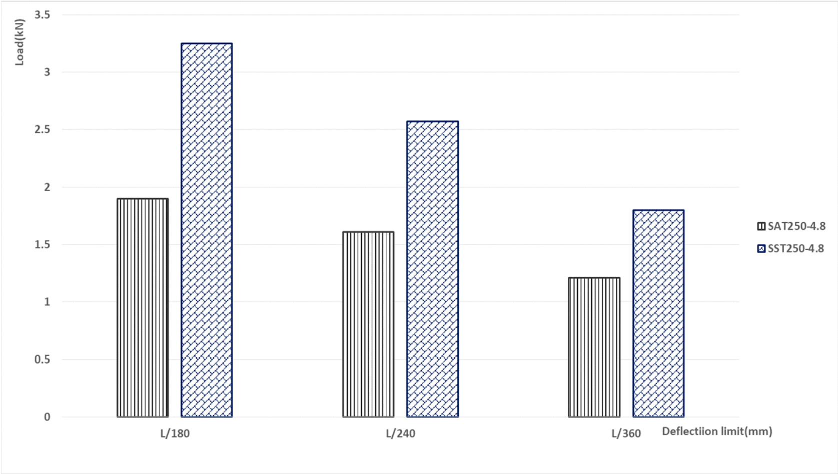

Fig. 8. Comparison of the loads at three deflection limits for SAT and SST specimens. SAT: S company's steel web.-Alternate installation-truss, SST: S company's steel web.-Successive installation-truss.

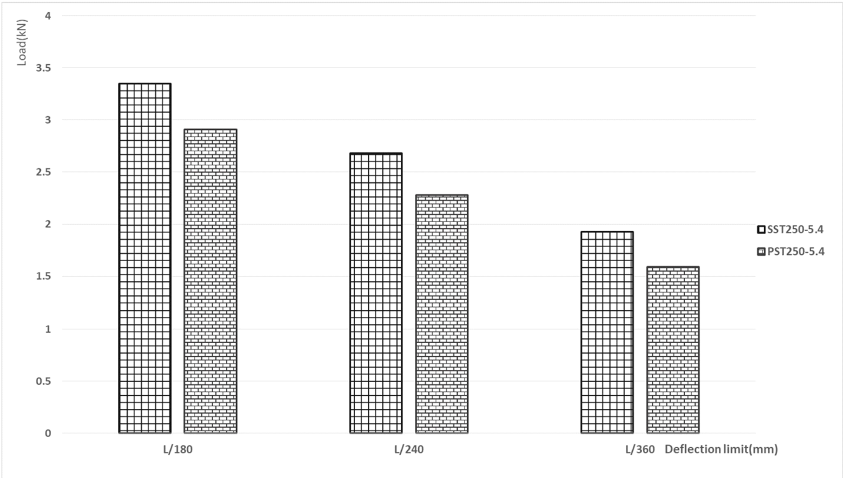

Fig. 9. Comparison of the load at deflection limits for different types of steel-web members.

steel-web members manufactured by S Co.). were higher than those of PST specimens (using steel-web members manufactured by P Co.). As described in Section 3.2., in all the test specimens, the steel-web members were bent by the shear force. Thus, this difference, which depends on the manufacturer of the steel-web member, is attributed to the material.

4. CONCLUSIONS

In this study, PCTSW specimens were constructed using timber chords and steel-web members. The bending strength of various types of PCTSW specimens according to their length and height, installation method of steel-web members, and type of steel-web member were tested according to KS F 2150. From the analysis of the test results, the following conclusions were drawn:

1) The load at deflection limits and the deflection limits themselves increased from L/180 to L/360 regardless of the lengths of specimens.
2) The load at deflection limits increased as the height of PCTSW specimens increased from 200 to 300 mm.
3) The successively installed steel-web members (SST) showed almost 2 times higher load at each deflection limit compared with that of SAT specimens (alternate installation of the steel-web members).
4) The load at each deflection limit for SST specimens (using steel-web members manufactured by S Co.) was higher than that of PST specimens (using steel-web members manufactured by P Co.).

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENT

Not applicable.

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