Theoretical behaviour of plate beams in pole frame farm buildings

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Massé, D.I., Lee, T., Salinas, J.J. and Munroe, J.A. 1992. Theoretical behaviour of plate beams in pole frame farm buildings. Can. Agric. Eng. 34:253-258. This study examines the behaviour of multi-member plate beams of the type commonly used in pole frame farm buildings. The design of these beams has been traditionally based on analysis techniques which are approximate in nature and make assumptions about behaviour which are uncertain and in some cases, not conservative. The theoretical investigation takes into consideration the semi-rigid behaviour of plate beam butt-joints, their location and the mode of support of the individual members. The results of a series of computer analyses show variation in bending moment distribution between interior and exterior members within multi-member plate beams depending on the mode of support. For multi-member plate beams where some members are supported on the end grain of notched poles and some on scabs nailed to the pole, those members supported on the end grain can exhibit much higher bending moments than those supported on the more flexible scabs resulting in an uneven and inefficient load distribution. It is assumed that the plate members are not nailed together along their length. The difference in bending moments is small when individual members are supported in the same mode, either on scabs or on pole end grain, but not on both.

This étude examine le comportement des poutres composées à âme pleine, du genre généralement utilisé pour construire la charpente des bâtiments de ferme à ossature de poteaux. La conception de ces poutres est normalement basée sur des analyses techniques de nature approximative, qui permettent d’émettre des hypothèses sur des comportements quelquefois incertains et non modérés. Les études théoriques tiennent compte du comportement semi-rigide des assemblages de poutres par boutage, de leur emplacement et du mode d’appui de chaque élément. Les résultats d’une série d’analyse par ordinateur montrent des variations dans la répartition du moment fléchissant entre les éléments intérieurs et extérieurs des poutres composées à âme pleine, selon le mode d’appui. Lorsque certains éléments sont appuyés sur le bois de bout de poteaux entaillés et d’autres sur des renforts de sablière cloués au poteau, le moment fléchissant des premiers peut être plus élevé que celui des seconds, ce qui produit une répartition inégale et inefficace des charges. Nous supposons que les poutres ne sont pas clouées les unes aux autres sur la longueur. La différence entre les moments fléchissants est peu importante lorsque les éléments sont tous appuyés de la même façon, c’est-à-dire soit sur le bois de bout de poteaux entaillés, soit sur des renforts de sablière cloués au poteau, mais pas sur ces deux genres d’appui à la fois.

INTRODUCTION

Multi-member plate beams are an important structural component of pole frame buildings. Located at the top of the pole, they support the rafters or trusses between poles. Current systems proposed for pole frame farm structures are two-span beams for pole spacing up to 2.4 m with joints occurring at the poles in a staggered or concurrent arrangement (Fig. 1). For larger pole spacings multi-member simple plate beams with joints occurring at the poles, or continuous plate beams with joints located between the poles at points of minimum bending moment are recommended.

Plate beams can be supported by either the poles, the scabs, or both the poles and scabs (Fig. 2). In some cases, the plate beam members are supported by notches in the poles. The process of making the notches and placing the beam members in them can be both lengthy and troublesome. Therefore, some builders prefer to simply place the beam members on scabs, which are nailed to the poles. In actual practice, the degree of fastening between adjacent plate members along their length can vary from nil to excessive.

Plate beam systems are typically designed using a traditional approximate approach. Moment coefficients can be selected from beam tables such as those shown in the Canadian Institute of Steel Construction Handbook of Steel Construction (CISC 1985). Such an analysis assumes that each member of a multi-member plate beam carries the same portion of load and therefore has the same bending moment and shear. This design procedure does not consider: 1) the effect of plate and pole end rotation and translation due to truss deflection under load, 2) the effect of plate beam eccentricity at the top of the pole, and 3) the effect of variation in the plate support stiffness which occurs when one plate member bears on a scab which is nailed to the pole, while another bears on the end grain of a notch in the pole. A study was therefore initiated to predict what the potential variation in load distribution among plate members could be due to the preceding factors.

OBJECTIVES

The objective of this study was to develop and carry out a detailed analysis of the typical plate beam systems used in pole frame farm structures. This improved analysis should be able to predict more accurately the load distribution among the individual members of the plate beam and thus the plate beam moment and shear distribution and coefficients. Also, it should be able to quantify the effect of truss deflection, plate eccentricity and location, and plate beam support (scab or pole, or both scab and pole). The most conservative case was considered wherein individual plate members were not
assumed to be adequately nailed, glued, or bolted together along their length to ensure they deflected as a unit.

**Literature review**

Turnbull (1968) prepared a guide for the design and construction of pole frame wall construction for farm buildings and Jackson and Turnbull (1975) later developed a quick design chart for pole frame sidewall plates. This simple design chart did not consider the shear strength of wood, and the capacity of the plate beam was independent of truss spacing. Darby et al. (1988) developed a more comprehensive design procedure for all practical combinations of plate beams. The procedure included consideration of the shear strength of wood and the spacing of the trusses. None of the studies above used an analog model in their design. Rather, their designs were based on traditional assumptions such as equal distribution of load, and no vertical deflection at supports.

**THEORY AND PROCEDURE**

Three-dimensional analog models that closely represent the real structure were developed to carry out a finite element analysis of the most popular plate beam systems used in pole frame farm structures. These models considered the effect of truss deflection, plate eccentricity and plate beam support.

The trusses were simply supported on the plate beam. Fixed connections were assumed between the beam and the poles, i.e. the plate was not free to rotate relative to the top of the pole. The bottom ends of the poles were assumed to be fully fixed at ground level (Fig. 3). Adjacent members of multi-member plate beams were assumed to not have been nailed, glued, or bolted together sufficiently to ensure uniform deflection.

The roof truss considered was a Fink truss with a span of 18 m and a slope of 1:3. Truss member sizes were 38 x 184 mm for the bottom chord, 38 x 235 mm for the top chord, and 38 x 89 mm for the webs. The plate beam members were 2-38 x 235 mm, and the pole was...
140 x 140 x 4800 mm. The truss and plate beam members were S-P-F No. 2 or better and the pole was North Species.

Analog models A and B in Fig. 3 represent two-member plate beam systems where the plate load is transferred directly to the end grain of the pole. The models were slightly modified to analyze three and four-member plate beam systems with the same type of support.

Analog model C in Fig. 3 represents a two-member plate beam supported by scabs only. The plate beam load is transferred to the scab and then to the pole. The scabs are represented in the analog model by axial springs. These springs are assumed to deform 1.27 mm at design load (Massé et al. 1988). The 1.27 mm of deformation represents the slip of the nail connection at design load. This design standard for nailed connections has been adopted by the Canada Plan Service for low human occupancy farm structures.

Analog models D and E in Fig. 4 represent plate beam systems where individual members bear on a combination of supports having different rigidities (scab and pole end grain).

In Figs. 3 and 4, numbers identify members of the analog model with different member properties. Member 1 was used to model both the bottom chord member and plate beam member. Since these members were subjected to compression perpendicular to the grain, the modulus of elasticity (MOE) perpendicular to the grain was obtained by taking one-eighth of the MOE given in the code for S-P-F No. 2 (USDA 1974).

Members 3 and 4 were used to model the top portion of the pole. Their lengths were 400 mm and 350 mm, respectively. Member 5 was used to model the scabs. A length of 50 mm was assumed. The cross sectional area had to be determined by performing iterations during the analysis to ensure that the net axial deformation was 1.27 mm.

Member 2 was used to model the transfer of the loads from the top outer portion of the pole to the bottom portion of the pole (Member 6). Member 2 is a rigid fictitious member with a length equal to the distance between the centerline of the plate beam members and the centerline of the pole.

Member 6 was used to model the bottom portion of the pole. The pole was assumed to be fully constrained (fixed) at ground level.

RESULTS

Moment distribution and coefficients
Analog model A in Fig. 3 was used to predict the moment distribution along both the two span and continuous plate beams. As shear is directly related to bending moment, the distribution of shear among the plate members would be similar to that of the moments. Figures 5 to 8 give the moment distribution and coefficients for plate beams with joints occurring at the poles in either a concurrent or staggered arrangement, and for truss spacings of either 600 or 700 mm.

Fig. 5. Bending moment diagrams and coefficients for a two-span multi-member plate beam with joints staggered at the poles; truss spacing is 600 mm.

Fig. 6. Bending moment diagrams and coefficients for a two-span multi-member plate beam with joints concurrent at the poles; truss spacing is 600 mm.
Fig. 7. Bending moment diagrams and coefficients for a two-span multi-member plate beam with joints staggered at the poles; truss spacing is 1200 mm.

Fig. 8. Bending moment diagrams and coefficients for a two-span multi-member plate beam with joints concurrent at the poles; truss spacing is 1200 mm.

Fig. 9. Bending moment diagrams and coefficients for a continuous plate beam system; truss spacing is 600 mm.

Fig. 10. Bending moment diagrams and coefficients for a continuous plate beam system; truss spacing is 1200 mm.

1200 mm. Figures 9 and 10 show results for a continuous beam with joints staggered at the quarter points of the pole spacing and for truss spacings of either 600 or 1200 mm. As shown in Figs. 5 to 10 the interior member of the two-member plate beam carries a higher portion of the bending moment. The interior member carries 54% of the total moment and the exterior member 46%. This difference is due to plate and pole end rotation and translation induced by truss deflection and plate beam eccentricity at the top of the pole. The moments carried by the interior member of the plate beams are about 8% larger than those suggested by Darby et al. (1988). Therefore, the moment values they have used were reasonable for plate beams that sit on the end grain of the pole.

Effect of support conditions

Figure 11 shows the portion of the plate load carried by the individual members when they bear on supports having the same axial rigidity. As shown in Fig. 11, cases A, B and C, the load distribution for two plates that bear on the pole end grain is similar to the load distribution for two plates that bear on the scabs.

In Fig. 11, cases A, C, D, and E show the load distribution for 2, 3 and 4-member plate beams that sit on the end grain of the pole. The variation of load distribution among the members is not negligible. This phenomena should be considered further in future studies relating to load capacity of multi-member plate beams.
Fig. 11. Load distribution among individual members of the plate beam, when members bear on supports having the same axial rigidities.

Fig. 12. Load distribution among individual members of the plate beam, when members bear on supports having different axial rigidities.

Fig. 13. Effect of eccentricity “e” of the plate location on the pole.

Composite supports (pole and scabs)
Analog models D and E in Fig. 4 represent plate beams where individual members sit on composite supports having different rigidities. Analog model E was modified to accommodate 3-member plate beams.

Figure 12 gives the load distribution for such plate beam systems. The load carried by plates that sit on a scab is substantially smaller than that carried by plates that sit on the end grain of the pole. The smaller axial stiffness of the scabs, hence greater deflection of that support, causes the member supported by the end grain of the pole to carry a higher portion of the total plate load. To achieve a uniform load distribution for plate beam members, supports should have the same axial stiffness. Members supported by both the poles and scabs should be avoided.
Effect of plate spacing

Analog model B in Fig. 3, was used to investigate the effect of plate spacing on the load distribution of two-member plate beam systems where members were located on both sides of the pole. As shown in Fig. 14, the load distribution changes only slightly as the spacing between the plate beam members changes.

Effect of plate beam location

Figure 15 shows the difference between placing the plate beams on the outside or inside of the poles. It can be seen that for plate beam members supported by the poles only, the difference (4-8%) in the load distribution is small. However, for plate beam members supported by both the poles and scabs, the difference is considerably higher.

CONCLUSIONS

1. There is a variation in the bending moments and shear between the interior and exterior members of a multi-member plate beam. The variation is small when the individual plate members sit on supports having the same axial rigidity but can be large when they sit on supports having different rigidities.

2. The effect on the load distribution due to eccentricity of the plate on the pole is small.

3. The effect of spacing between plate beam members on the load distribution is small.

4. The difference in the load distribution among the beam members is the smallest when the beam members are supported by either the poles only or the scabs only.

5. For plate beams supported by both the poles and scabs, the beam members supported by the poles carry a substantially higher portion of the total load because the axial stiffness of the poles is larger than the apparent axial stiffness of the scabs.

6. The most uniform load distribution among beam members is achieved when members are supported by either scabs only or the poles only.

REFERENCES


