WCTE 2014
Quebec City Canada August 10-14
World Conference on Timber Engineering

LOAD DISTRIBUTION IN LATERAL LOAD RESISTING ELEMENTS OF TIMBER STRUCTURES

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ABSTRACT: Stiffness properties of diaphragm and lateral load resisting elements (LLREs) influence the load distribution between LLREs under lateral load induced by earthquake or wind. Where a more sophisticated method of calculating the load distribution in a lateral load resisting system is used, often it is based on the concept of beam on elastic foundation. This approach could be tedious to apply in design when there are several LLREs. A multiple spring model (MSM), where translational springs are used to model the diaphragm stiffness and the stiffness of the LLREs, is proposed. The developed model was validated with results from a more sophisticated analysis using a finite element program. The lateral load distribution between LLREs with various stiffness ratios of diaphragm to LLREs and considering the torsional effects was also investigated. The results show that, contrary to common belief, the forces transferred by a semi-rigid diaphragm to the supporting LLREs may be higher than those predicted by flexible and rigid diaphragm assumptions. Hence using the envelope force approach proposed by some may lead to underestimation of the design forces in the shearwalls.

KEYWORDS: Timber structures, Structural elements, Diaphragms, Load distribution.

1 INTRODUCTION

In building structures that contain a number of different lateral load resisting elements (LLREs), the distribution of the lateral loads arising from wind and earthquake is dependent on the stiffness characteristics of the horizontal diaphragms relative to that of the LLREs supporting the diaphragms.

Figure 1 shows a single-storey building under a uniform load, *p*. The diaphragm acts as a load distributor to the LLREs that run parallel to the direction of applied lateral load and transfers the shear force down to the foundation. How the lateral load shared between the LLREs depends in principle, on the flexibility of the diaphragm relative to that of the supporting LLREs. In design, if the diaphragm is idealized as 'rigid', all LLRE's are assumed to deform by the same amount, and therefore the lateral load is distributed to each LLRE in proportion to its stiffness. As a result, a stiffer LLRE would attract a higher proportion of the applied lateral load. If the diaphragm is assumed 'flexible', the LLREs deform by different amounts and the lateral load resisted by each LLRE will be assigned based on the respective tributary area. Whilst the assumptions of rigid and flexible diaphragms are convenient from a design perspective, reality is that wood-based diaphragms are often semi-rigid, which significantly complicates the calculation of forces resisted by LLREs.

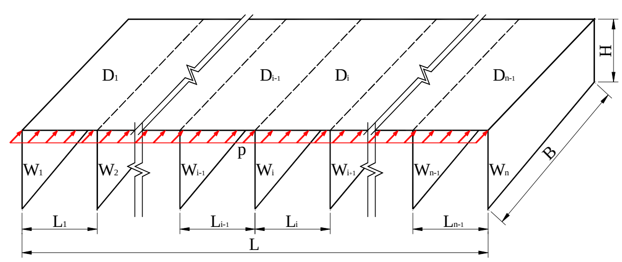

Figure 1: *Single-storey building*

To date, limited research has been undertaken to systematically evaluate the diaphragm flexibility and its influence on the load distribution to LLREs. In this study, a multiple spring model is proposed for estimating the load distribution between LLREs with different stiffnesses. Some preliminary conclusions regarding the inadequacy of the current design approach are given.

2 MULTIPLE SPRING MODEL

An established approach to estimate the distribution of lateral loads to individual LLREs is the beam-on-elastic-

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foundation concept. For a simple building with only a few LLREs, solutions of the deep beam-on-springs model (DBSM) for design purposes can be obtained with relative ease. However, as the number of diaphragm elements and LLREs increases, more sophisticated analysis procedures, such as finite element analysis (FEA), may be required which makes this method not very user friendly.

To address the limitations of the DBSM approach, a multiple spring model (MSM) is proposed. In the MSM, as illustrated in Figure 2 for a single-storey building, each LLRE is modelled by a translational spring with stiffness K_i connected to the ground. Similarly the diaphragm between adjacent LLREs is modelled by a translational spring with stiffness K_{Di}, which is connected to the springs representing the two adjacent LLREs via a rigid beam with only one degree of freedom in the direction of the applied load.

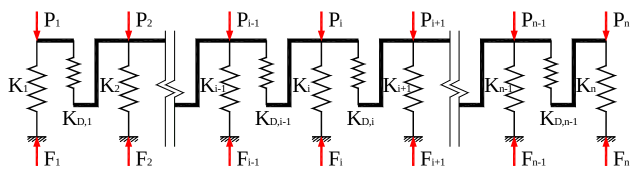

Figure 2: *Multiple spring model for single-storey buildings*

The reactions and deformations of the LLRE springs in this MSM can be obtained by solving the system of equations with 2n variables, as shown in Equation (1).

$$\{F\}_{2n} = [D]_{2n\times 2n}\{U\}_{2n} \quad (1)$$

Equation (1) can be solved numerically by applying the Gaussian Elimination Method. The solution routine can be implemented in a simple computer program.

3 LOAD DISTRIBUTION IN LLREs

To verify the proposed MSM and to investigate the load distribution between LLRE's, two types of single-storey building with and without consideration of the torsional effects and with different LLREs arrangements were analysed under a uniform lateral load.

The DBSM was used as the reference analysis method. The force ratios, α_F, defined as the ratio of the reaction force of any individual LLRE to those of the all LLREs, of the building cases predicted by the MSM agree well with those predicted by FEA of DBSM using ABAQUS [1]. As shown in Figure 3, the range of the semi-rigid diaphragm is much wider than assumed in the codes [2-3], and as a result, diaphragms in most timber structures should be classed as semi-rigid.

An interesting observation in both the MSM and the FEA results shown in Figure 3 is that the force ratio of some of the internal springs in the semi-rigid range was higher than the values at the two extreme regions, i.e. rigid and flexible. Therefore, the design method using the envelope force of the two diaphragm flexibility assumptions, as proposed by APEGBC [4], may not always be conservative.

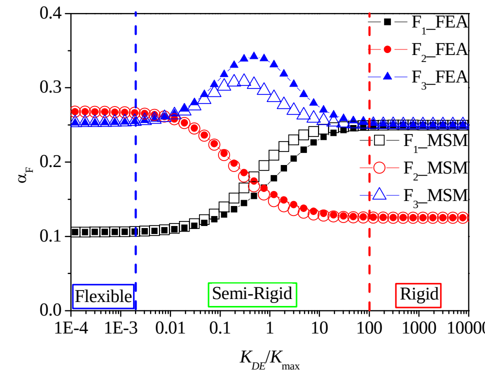

Figure 3: *Force ratio vs. stiffness ratio*

Note: K_{DE} is the equivalent stiffness of diaphragm, while K_{max} is the largest stiffness of LLREs.

4 CONCLUSION

In this paper, a simplified mechanics-based model consisting of multiple springs to represent the stiffness of diaphragms and supporting LLREs, is proposed for calculating load distribution to LLREs. Comparison between results based on the MSM and those obtained from FEA has shown that the proposed model is adequate for design use. In addition, the results shown here reveal that the design method based on envelope forces may not always be conservative.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the financial support provided by Natural Sciences and Engineering Research Council (NSERC) of Canada under the Strategic Research Network on Innovative Wood Products and Building Systems (NEWBuildS).

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