A Method for Incorporating Live Load Reduction Provisions in Frame Analysis

RONALD D. ZIEMIAN and WILLIAM McGUIRE

INTRODUCTION

The effects of live load are often reduced to reflect the low probability of all live load existing simultaneously throughout a substantial portion of a structure. Subject to certain limitations, ASCE 7-88[1] provides the following permissible reduction

$$L = \left(0.25 + \frac{15}{\sqrt{A_I}}\right)L_o \geq \alpha L_o \qquad (1)$$

where:

L = reduced design live load
A_I = member influence area in square feet ($A_I \geq 400$ ft^2)
L_o = unreduced design live load
α = 0.5 for members supporting one floor and 0.4 otherwise

In the analysis of entire structural systems or substantial portions thereof, methods for incorporating live load reduction are essential. They can have a significant influence on a structure's response. Not to include live load reduction provisions may be overly conservative. For example, reduced live loads may produce smaller second-order effects. In some cases, however, use of full live load may be unconservative. For example, full live load may not be in place to resist an overturning moment produced by lateral load.

The incorporation of live load reduction provisions of the type in ASCE 7-88 requires careful consideration when analyzing structural systems. This is because (i) the influence area for beams and columns are generally different, and (ii) Eq. 1 is a nonlinear function of this area. Several methods for including live load reduction in system analyses have been suggested.[2,3,4] These methods, however, have only treated reduction of member forces for the purpose of member proportioning. Also, they may produce member forces that are not consistent with the calculated deflections of the frame. With this in mind, a more comprehensive method for incorporating live load reduction in system analyses has been developed.[5]

Ronald D. Ziemian is assistant professor of civil engineering, Bucknell University, Lewisburg, PA.

William McGuire is professor of civil engineering, emeritus, Cornell University, Ithaca, NY.

OUTLINE OF APPROACH

The method is based on the use of "compensating forces" calculated by: (a) applying beam live load reduction factors to the column connected beams; (b) applying column live load reduction factors to the columns; and (c) determining any out of balance at the beam-to-column intersections. Because columns typically have a larger influence area than beams (providing for a larger reduction), the compensating forces are generally upwardly directed (opposite of gravity). All structural system analyses which include live load are then performed by applying a combination of the reduced beam live loads and the calculated compensating forces. By applying this combination of live load, the resulting forces

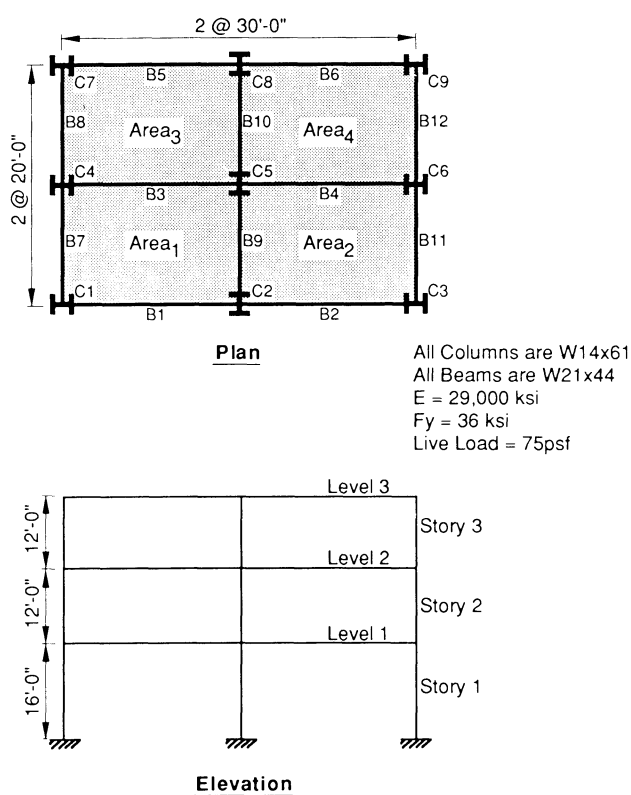

Fig. 1. Description of example frame.

in both the main girders and the columns will reflect the ASCE-7 live load reduction provisions.

The frame shown in Fig. 1 will be used to illustrate the determination of compensating forces. Each of the relevant structural components in the frame is assigned a two part identifier. The first part, a beam, column, or area number, is defined in the plan view of Fig. 1. The second part, the level (for beams and areas) or story (for columns), is provided in the corresponding elevation view. For example, the member designation B1-3 refers to **B**eam **1** of level **3,** and C2-1 refers to **C**olumn **2** of story **1.**

The following steps outline how the live load compensating forces could be calculated:

1. Based on tributary area, estimate the axial force in each column without applying any reduction factors. For column C2-1 (see Fig. 2), an estimate of the unreduced axial force is

$$F_{C2\text{-}1} = \tfrac{1}{2}\sum_{i=1}^{3}[(\omega_{B1\text{-}i} \times L_{B1\text{-}i}) + (\omega_{B2\text{-}i} \times L_{B2\text{-}i}) + (\omega_{B9\text{-}i} \times L_{B9\text{-}i})] \quad (2)$$

where:

$\omega_{Bj\text{-}i}$ = unreduced uniform live load along beam Bj-i
$L_{Bj\text{-}i}$ = length of beam Bj-i

(In lieu of assuming one-half of the beam loads contributing to each of the column forces, a structural analysis that accounts for the actual continuity of the system could be performed to obtain a more accurate estimate of the column axial force distribution).

2. Based on each column's influence area, reduce the above axial force by the ASCE 7-88 live load reduction factor (Eq. 1). For column C2-1, the reduced axial force is

$$F'_{C2\text{-}1} = \left(0.25 + \frac{15}{\sqrt{\sum_{i=1}^{3}(\text{Area}_{1\text{-}i} + \text{Area}_{2\text{-}i})}}\right)F_{C2\text{-}1} \quad (3)$$

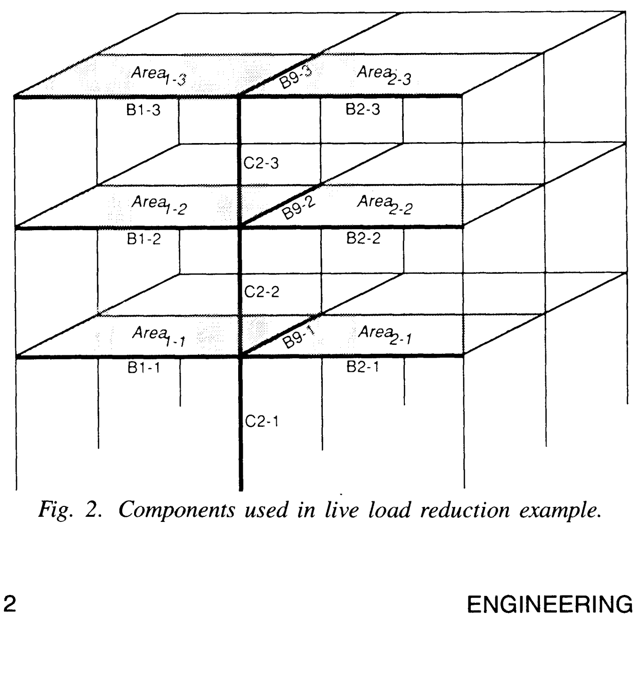

Fig. 2. Components used in live load reduction example.

where:

$\sum_{i=1}^{3}(\text{Area}_{1\text{-}i} + \text{Area}_{2\text{-}i})$ = total influence area for column C2-1.

Note that $F'_{C2\text{-}1}$ should not be less than $0.4F_{C2\text{-}1}$.

3. Based on tributary area, estimate the axial force in each column by applying only beam live load reduction factors. For column C2-1, this axial force is approximately

$$F''_{C2\text{-}1} = \tfrac{1}{2}\sum_{i=1}^{3}[(\omega''_{B1\text{-}i} \times L_{B1\text{-}i}) + (\omega''_{B2\text{-}i} \times L_{B2\text{-}i}) + (\omega''_{B9\text{-}i} \times L_{B9\text{-}i})] \quad (4)$$

where:

$\omega''_{Bj\text{-}i}$ = reduced uniform live load along beam Bj-i
$L_{Bj\text{-}i}$ = length of beam Bj-i

As in step 1, a separate structural analysis could be performed to obtain a more accurate estimate of these column axial forces.

4. Determine the difference in axial forces calculated in steps 2 and 3. For column C2-1, this force is

$$F'''_{C2\text{-}1} = F''_{C2\text{-}1} - F'_{C2\text{-}1} \quad (5)$$

5. Determine the additional upward axial force, compensating force, to be applied at the top of each column segment. For column C2-1, this force is

$$f_{C2\text{-}1} = F'''_{C2\text{-}1} - \sum_{i=2}^{3} f_{C2\text{-}i} \quad (6)$$

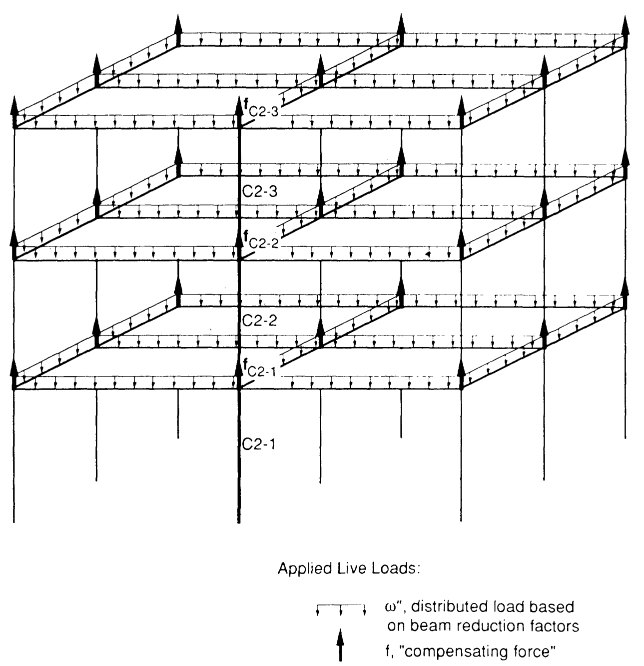

Fig. 3. Description of applied live load to be used in frame analysis.

Table 1.
Example of Reduced Live Load Calculations

(a) Beams

Member	Length ft	Tributary Area ft^2	ω, Unreduced Uniform L.L. k/ft	Influence Area ft^2	Permissible Reduction Factor	ω'', Reduced Uniform L.L. k/ft
B1-i, B2-i	30	200	0.500	600	0.862	0.431
B9-i	20	200	0.750	1200	0.683	0.512
for i = 1 to 3						

(b) Columns with Force Distribution Estimated

Member	F, Unreduced Axial L.L. kips	Influence Area ft^2	Permissible Reduction Factor	F', Reduced Axial L.L. kips	F'', Reduced Axial L.L. kips	$F''' = F'' - F'$ kips	f, Compensating Force (Upward) kips
C2-1	67.50	3600	0.500	33.75	54.15	20.40	9.32
C2-2	45.00	2400	0.556	25.02	36.10	11.08	8.40
C2-3	22.50	1200	0.683	15.37	18.05	2.68	2.68

(c) Columns with Force Distribution Determined by Linear Elastic Analysis

Member	F, Unreduced Axial L.L. kips	Influence Area ft^2	Permissible Reduction Factor	F', Reduced Axial L.L. kips	F'', Reduced Axial L.L. kips	$F''' = F'' - F'$ kips	f, Compensating Force (Upward) kips
C2-1	69.48	3600	0.500	34.74	55.71	20.97	9.59
C2-2	46.45	2400	0.556	25.83	37.21	11.38	8.56
C2-3	23.37	1200	0.683	15.96	18.78	2.82	2.82

A summary of typical forces used in this frame's live load calculations are provided in Tables 1(a) and 1(b). Figure 3 shows the net applied live load distribution. Table 1(c) shows distributions obtained by calculating the forces for steps 1 and 3 by a three-dimensional linear elastic analysis of the rigidly jointed system.

In all cases where factored load combinations are investigated, both the beam live loads and the compensating forces should be multiplied by the appropriate live load factors.

SUMMARY

An approach for incorporating live load reduction provisions within system analyses is presented. By determining an appropriate applied live load, the resulting forces in both the beams and the columns will include the ASCE 7-88 live load reduction provisions. In applying this live load, any displacements calculated by a structural analysis will be consistent with the reduced internal member force distribution. Joint equilibrium will be maintained. Because the procedure does not rely on applying the principle of superposition, it may be used with either linear or nonlinear structural analyses.

The concept of compensating forces has been illustrated by applying them at beam-to-column intersections only. The same idea can be extended to accommodate any desired degree of modeling of interior floor framing.

ACKNOWLEDGMENTS

This research was supported by the National Science Foundation under Grant Number MSM-8608803, the American Institute of Steel Construction, and the School of Civil and Environmental Engineering at Cornell University. The authors wish to thank Dr. Jerome F. Hajjar of Skidmore, Owings and Merrill for his comments and suggestions.

REFERENCES

1. *American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures,* ASCE 7-88, American Society of Civil Engineers, New York, 1990 (formally, *American National Standard Minimum Design Loads for Buildings and Other Structures,* ANSI A58.1, American National Standards Institute, New York, March 1982).
2. Parikh, B. P., "Elastic-Plastic Analysis and Design of Unbraced Multi-Story Steel Frames," Ph.D. Thesis, Lehigh University, June 1966.
3. Pesquera, C. I., "Integrated Analysis and Design of Steel Frames with Interactive Computer Graphics," Ph.D. Thesis, Cornell University, Ithaca, New York, March 1984.
4. White, D. W. and Hajjar, J. F., "Application of Second-Order Elastic Analysis in Design—Research to Practice," AISC, National Steel Construction Conference, Kansas City, Missouri, March 1990, pp. 11.1–11.22.
5. Ziemian, R. D., "Advanced Methods of Inelastic Analysis in the Limit States Design of Steel Structures," Ph.D. Thesis, Cornell University, Ithaca, New York, August 1990.