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LIVE LOAD REDUCTION IN THE DESIGN OF HIGH-RISE BUILDINGS

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ABSTRACT : A review of provisions of different codes regarding the reduction of live loads on various structural members of high-rise buildings is presented. The codes and the standards reviewed are UBC-1991, ANSI-A58.1, AS1170.1-1971, NBC-Canada-1985, BSI-CP3-1972, NBC-India-1983 and the Bangladesh National Building Code(BNBC)-1993. All these codes have permitted reduction in live loads for primary structural members such as beams, columns, piers, footings etc. supporting building floors. In BNBC, all possible live loads applied to floors and roofs of building due to various occupancies and uses are divided into three load groups. The live load reduction factors are provided in tabular form for various load groups based on the tributary area of the floor or the roof or combination thereof. The total reduced live load on a structural member is determined by summing up the reduced live loads from each load group. The reduced live loads are obtained by multiplying the code live loads by the corresponding reduction factors. The application of live load reduction according to various codes is illustrated through sample problems.

KEYWORDS: Live Load, Building Codes, High-rise Buildings, Reduction Multiplier, Load Group

INTRODUCTION

The weight of the building itself imposes loads on the structure which are called dead loads and remain constant for the life of the building unless the building undergoes major renovation. Occupancy loads also impose gravitational effects, which vary because of the changing occupancy of the floors. These are called live loads and include the effect of people and furniture. Unlike dead loads, live loads can not be accurately predicted but can only be estimated. These are dictated by building codes based on structure type and occupancy.

The live-loads given in the codes have considered empirical safety factors to account for maximum possible loading conditions and are given in the form of equivalent uniform loads and prescribed concentrated loads. Concentrated loads indicate possible single-load action at critical locations and are in addition to the uniformly distributed load. It is perhaps obvious that the chances of having the full occupancy load simultaneously on every square foot of a large area in a building are next to zero. The larger the area under consideration,

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the less is the potential for having full live load. This probability aspect is taken into consideration in the codes by allowing the use of live-load reduction factors.

PROVISIONS OF LIVE LOAD REDUCTIONS IN BUILDING CODES

Almost all codes of practice allow reduction in live loads in different forms. Some codes recommended reduction of live loads at the same rate on all the floors above the member under consideration, where the rate of reduction depends on number of floors supported by the member. Some of the code provisions suggest successive reduction on floors with a limitation of maximum reduction. For example, the British Code of Practice BS-CP3, National Building Code of India suggest the above approach commonly known as "Percentage Method".

Another form of live-load reduction method commonly known as "Dead Load to Live Load Ratio Method" has been adopted by Uniform Building Code UBC-91 and Australian standards AS 1170, part 1-1971. In this method it is assured that the structural members will not fail or stress to the yield point which had been designed on the basis of reduced live load when full live load happen to occur over the entire area supported by the said structural element.

Tributary Area Method is another form of live load reduction approach as adopted by BNBC - 93 and Uniform Building Code of Canada. American National Standards Institute (ANSI) A 58.1 has adopted the influence area rather than a tributary area for evaluating the amount of reduction permitted. This form of live-load reduction provides for i) increased reduction with increased tributary/influence area, ii) lesser rate and reduction for storage and commercial areas than residential, office areas, iii) an upper limit to the reduction and iv) the exclusion of certain loads for probable full contribution. The Provisions of live load reduction methods as given in major codes are outlined in brief below:

Uniform Building Code, UBC-1991

Reduction of live load is permitted by the code under certain conditions for members supporting an area more than 150 ft^2 (13.95 m^2) including flat slabs except for floors in places of public assembly and for live loads greater than 100 psf (4.8 kpa), in accordance with the following formula:

$$R = r\,(A_t - 150), \text{ but not greater than } 23.1(1+D/L)$$

In the above formula,

R = reduction in percentage

r = rate of reduction equal to 0.08 for floor and equal to 0.06 or 0.08 for roof.

A_t = tributary area in square foot of floor or roof supported by the member

D = dead load per square foot of area supported by the member

L = live load per square foot of area supported by the member.

Maximum reduction allowed 40 percent for members receiving load from one level only, 60 percent for the other members. For storage live loads exceeding 100 psf (4.8 kpa) no reduction is permitted, except that design live loads on columns may be reduced 20 percent.

American National Standards Institute, ANSI A-58.1, 1982

This code permits, with some limitations discussed below, a reduction in live load for members having an influence area of 400 ft^2 (37.16 m^2) or more. The reduced live load, L is obtained from the relation $L = L_o (0.25 + 15/\sqrt{A_i})$, where L_o is the unreduced design live load and A_i is the influence area rather than a tributary area in square ft. For an interior column, the influence area is the total floor area of the four surrounding bays (four times the traditional tributary area). For interior beams the influence area consists of the two adjacent panels, while for the peripheral beam, it is only one panel. The reduced live load should be not less than 50% of the unit live load L_o for members supporting one floor nor less than 40% of L_o otherwise. Using the above ANSI expression for reduced live load, the reduction multiplier (RM) as a function of influence area is plotted in Fig.1. In high-rise buildings, the influence areas for columns supporting more than one floor are summed.

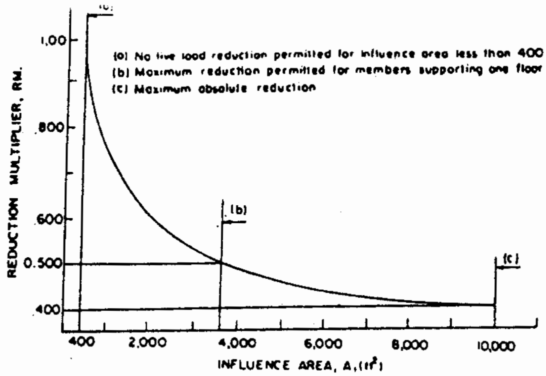

Fig. 1. Reduction Multiplier (RM) for Live Loads

Limitations on Live-Load Reduction

For live load of 100 psf (4.8kpa) or less, no reduction is allowed for areas to be occupied as places of public assembly, for garages. For live loads on members supporting more than one floor may be reduced 20%, but loads in other cases should not be reduced.

National Building Code of Canada, 1990

No reduction is allowed for the following cases:

i) Assembly occupancy with live load less than 4.8 kpa (100 psf).
ii) Assembly occupancy with a live load of 4.8 kpa (100 psf) or more and tributary area A_t =80m^2 (860 ft^2).
iii) Storage, manufacturing, retail stores, garages or as a foot bridge with A_t =80m^2 (860 ft^2).

Limited reduction is allowed for the following cases in accordance with the formula

$R = 0.5 + \sqrt{20/A_t}$

i) Assembly occupancy with Live Load = 100 psf (4.8 kpa).
ii) Storage, manufacturing, retail store, parking garage with A_t =80m^2 (860 ft^2).

Where a structural member supports a tributary area of floor, roof or combination of these greater than 20 m^2 (215 ft^2) for any use or occupancy other than assembly occupancies and those indicated above, the live load should be reduced

$$R = 0.3 + \sqrt{9.8/A_t}$$

where R is the reduction in percentage and A_t is the tributary area in square meters.

Australian Code AS 1170, part 1-1971

The Australian standards AS 1170-1971 recommended the live load reductions in a similar way as given by UBC - 91. This standard further adds that in the case of multi-storey buildings in which the live load varies from floor to floor or varies between defined areas within a floor, the appropriate live load reduction shall be taken for each floor or defined area and these reductions shall be made cumulative.

British Code of Practice, BSI CP3

This code suggests a percent reduction of 0, 10, 20, 30, 40 and 50 for members (columns, piers, walls etc.) supporting 1, 2, 3, 4, 5 to 10 and more than 10 floors respectively. Single span beam or girder supporting not less than 46 m^2 (495 ft^2) of floor, it is permissible to reduce the specified live load by 5% for every 46 m^2 (495 ft^2) of floor supported; the maximum reduction being 25%. This reduction does not apply to floors used for storage, office floors used for filing and the like.

National Building Code of India

National Building Code of India, recommends the reduction in almost the same way as BSI-CP3 except the provisions of 40 percent reduction for members supporting five or more floors.

Bangladesh National Building Code, (BNBC) 1993

All possible live loads (shown in Appendix) applied on floors and roof of a building due to various occupancies and uses are divided into three load groups. Load group 1 comprises the uniformly distributed live loads arising from

i) assembly occupancies or areas with uniformly distributed live load of 5.0 kN/m^2 or less

ii) machinery and equipment for which specific live load allowances have been made

iii) special purpose roofs which are used for promenade purposes, assembly purposes, garden etc.

iv) printing plants, vaults, strong rooms and armouries

Load group 2 comprises uniformly distributed live load resulting from

i) assembly areas with uniformly distributed live load greater than 5.0 kN/m^2

ii) storage, mercantile, industrial and retail stores

Uniformly distributed live loads other than those of Load group 1 & 2 are categorised into Load group 3.

No reduction of live load is allowed for members or portions thereof under load group 1. Live load reduction factor $1.0 = R = 0.7$ is permitted for load group 2 in accordance with the following formula

$$R = 0.6 + \sqrt{8/A_t}$$

For load group 3, the live load reduction factor is given by

$$R = 0.25 + \sqrt{14/A_t} \quad \text{but } 1.0 = R = 0.5$$

Where A_t is the sum of all tributary areas in square meters with loads from any one load group. The appropriate live load reduction factor, R, is also given in tabular form in BNBC -93

RESULTS AND DISCUSSIONS

Two example problems shown in Figs. 2 and 3 are analysed to determine the live load reduction multiplier by different codes. The example problem 1 (Fig.2) is a 10 - storey commercial building with 20-ft square bays and the example problem 2 (Fig. 3) is a 15 - storey apartment building with 10-ft by 15-ft grid.

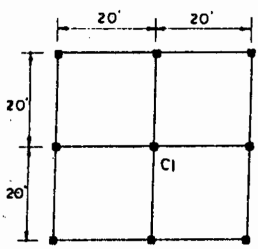

Fig. 2. Plan of Example Problem 1

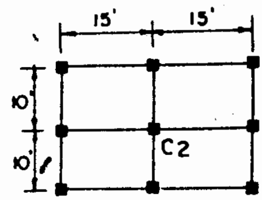

Fig. 3. Plan of Example Problem 2

For example problem 1, the uniformly distributed live loads for general office room is assumed 60 psf. The interior column C_1 shall be designed for a total live load of $(.06 \times 400 \times 10)$ = 240 kip, if live load reduction is not taken into account. Whereas the maximum live load that may come to column C_1 is 168 kip from BSI-CP3 code and according to BNBC, the maximum load is 137.6 kip. The average live load reduction multiplier (RM) is maximum in British Code and minimum in UBC-91 code. The value of RM in BNBC-93 is about 18% lower than BSI CP-3 and 2.7%, 11.6% and 21.9% higher than Building code of Canada, ANSI A58.1 and UBC-91 codes respectively. The value of reduction multiplier by different codes for the interior column C_1 is given in Table 1 and plotted in Fig. 4.

Table 1. Live load Reduction Multiplier (RM) for interior Column C1 of a 10-Storey Building (20 ft. square bays)

Storey	Tributary area		Influence Area	Reduction Multiplier RM				
	ft^2	m^2	ft^2	BNBC-93	UBC-91	ANSI A58.1*	Canada	BSI CP-3
10 (Roof)	406	37.18	-	0.864	0.80	1.0	0.813	1.0
9	800	74.36	1600	0.684	0.48	0.625	0.663	0.9
8	1200	111.54	3200	0.604	0.4	0.515	0.596	0.8
7	1600	148.72	4800	0.557	0.4	0.467	0.557	0.7
6	2000	185.90	6400	0.524	0.4	0.438	0.530	0.6
5	2400	223.08	8000	0.501	0.4	0.418	0.510	0.6
4	2800	260.26	19600	0.5	0.4	0.403	0.494	0.6
3	3200	297.44	10,200	0.5	0.4	0.4	0.482	0.6
2	3600	334.62	12,800	0.5	0.4	0.4	0.471	0.6
1	4000	371.80	14,400	0.5	0.4	0.4	0.462	0.6
		Total		5.734	4.48	5.066	5.578	7.0
		Average		0.5734	0.448	0.5066	0.5578	0.700

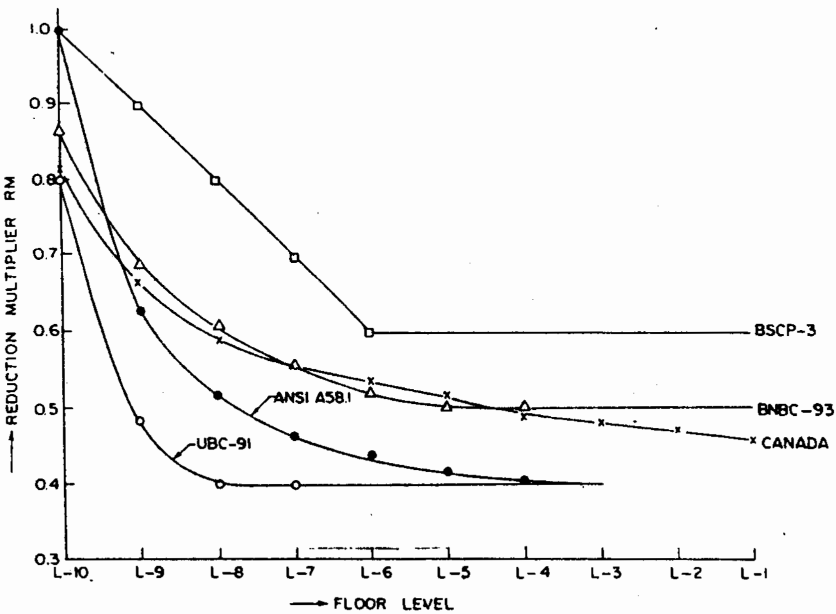

Fig. 4. Reduction Multiplier for Interior Column of a 10-Storey Building (20ft Square Bay) by Different Code Methods

For the 15-Storeyed apartment building (example problem 2), assuming the uniformly distributed live load as 40 psf, the column C_2 shall be designed for a maximum live load of $(0.04 \times 150 \times 15 x 0.662)$= 59.58 kip instead of 90.0 kip when live load is not reduced. The average live load reduction multiplier is maximum in BNBC-93 and minimum in UBC-91 code. The value of RM in BNBC-93 is about 2.0%, 4.4%, 16.8% and 21.5% higher than Building Code of Canada, BS-CP3, ANSI A58.1 and UBC-91 codes respectively. The reduction multiplier by different codes for column C_2 is given in Table 2 and plotted in Fig.5.

Table 2. Live load Reduction Multiplier (RM) for interior Column C2 of a 15-Storey Building (10ft. x 15 ft. grid)

Storey	Tributary area		Influence Area	Reduction Multiplier RM				
	ft^2	m^2	ft^2	BNBC-93	UBC-91	ANSI A58.1*	Canada	BS CP-3
15 (Roof)	150	13.94	-	1.0	1.0	1.0	1.0	1.0
14	300	27.89	600	0.958	0.88	0.862	0.893	0.9
13	450	41.83	1200	0.829	0.76	0.683	0.784	0.8
12	600	55.77	1800	0.751	0.64	0.604	0.719	0.7
11	750	69.71	2400	0.698	0.52	0.556	0.675	0.6
10	900	83.66	3000	0.659	0.40	0.524	0.642	0.6
9	1050	97.60	3600	0.629	0.40	0.500	0.617	0.6
8	1200	111.54	4200	0.604	0.40	0.481	0.596	0.6
7	1350	125.48	4800	0.584	0.40	0.467	0.579	0.6
6	1500	139.43	5400	0.567	0.40	0.454	0.565	0.6
5	1650	153.37	6000	0.552	0.40	0.444	0.553	0.5
4	1800	167.31	6600	0.539	0.40	0.435	0.542	0.5
3	1950	181.25	7200	0.528	0.40	0.427	0.533	0.5
2	2100	195.20	7800	0.518	0.40	0.420	0.524	0.5
1	2250	209.14	8400	0.509	0.40	0.414	0.516	0.5
		Total		9.925	7.8	8.271	9.738	9.5
		Average		0.662	0.520	0.551	0.649	0.633

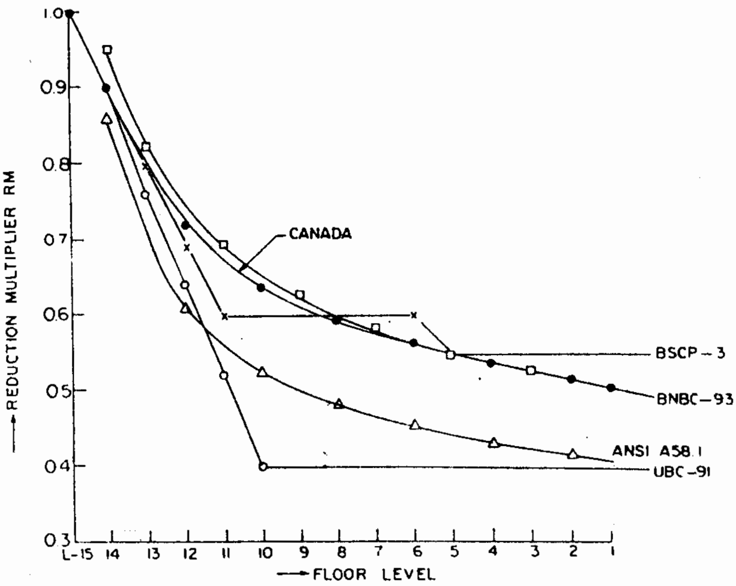

Fig. 5. Live Load Reduction Multiplier for Column of a 15-Storey Apartment Building by Different Code Methods

CONCLUSIONS

Several codes have been reviewed and salient features of their live load reduction methods have been presented. All possible live loads in BNBC are grouped into three categories. Tributary area of a structural member supporting floors or roof are clearly defined. Depending on the load group and tributary area, the appropriate live load reduction factors can be easily determined from the Tables provided in the Code. From the comparative study, BNBC approach is found to be more rational and realistic to determine the reduced live load on a structural member. The values of reduction multiplier in BNBC for the sample problems studied are found to be in good agreement with those of Building Code of Canada. Code values of live load shall be reduced for economic design of the primary structural members supporting floor or roof, including beam, girder, truss, flat slab, flat plate, column, pier footing and the like in the design of multi-storeyed buildings.

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