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Structural Design of Box Beam Header

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ABSTRACT

To obtain a design data for box beams used as headers in light-frame timber construction, 2×6 (38×140mm), 2×8 (38×184mm), 2×10 (38×235mm) and 2×12 (38×286mm) members were built as box beam specimens for bending tests. The allowable bending stresses for box beams were obtained through bending tests of these specimens, and span tables were calculated for various loading conditions based on the allowable bending stresses obtained. The allowable bending stresses were determined as the bending stresses at 10mm deflection of specimens from the results of bending tests of box beam specimens. Span tables for box beams were obtained assuming five loading conditions for headers used in exterior walls and two loading conditions for headers used in interior walls. Among these 7 loading conditions, 5 loading conditions applied to headers in exterior walls included the dead loads, the live loads and the snow loads and 2 loading conditions applied to headers in interior walls included the dead loads and the live loads.

Key words: Box beam, Header, Allowable bending stress, Span table.

INTRODUCTION

Lots of doors and windows having various sizes are used in wood constructions and openings shall be made by cutting studs in wall structures to install doors and windows. However, studs in wall structures will support vertical loads such as dead loads, live loads and snow loads and safely transfer them to foundation. Therefore, if openings are installed by cutting studs in wall structures, loads cannot be transferred through studs which may cause concentration or eccentricity of loads and may even affect the overall safety of buildings. To prevent these problems caused by cutting studs, headers are installed on the top of openings so that loads transferred through the cut studs can be safely transferred to the structures located below the openings by bending properties of headers.

Therefore, the members used as headers are performed as beams under loads and the bending properties are the most important characteristics of the members used as headers. In general, built-up beams or box beams constructed by the structural lumbers used for wood construction are used as headers. For headers made of built-up beams, span tables are included in the Building Codes of various countries (AF&PA, 2005) (ICBO, 1997 and 1998) (ICC, 2003 and 2003) (CWC, 2005) and, in our country, the span tables for built-up beams are included in Korean Building Code-Structural (Architectural Institute of Korea, 2005 and 2006).

Box beams are also used as headers in wood constructions but span tables for box beams are not included in the Building Codes or Standards. To make box beams, structural lumbers are used

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as flange members and, for web members, plywood, OSB or structural lumbers can be used. In built-up headers, insulation cannot be used inside of headers which may cause low insulation properties but, in box beam headers, insulation can be filled inside of headers which cause high insulation properties of box beam headers compared to built-up headers. Box beams made of panel webs are already formulated as KS F 3027 (Korea Standard Association) which includes the allowable properties in accordance with composition methods. However, although box beams with structural lumber webs are used widely in wood constructions, the allowable properties or span tables are not included in the Building Codes or Standards yet.

In this study, the advantages and disadvantages of various composition methods of box beams used as headers will be analyzed and their bending properties will be evaluated by bending tests. Span tables will be developed depending on the composition method and dimensions of members by analyzing the results of bending tests and used so that they can be used as convenient reference of header designs.

MATERIALS AND METHOD

In this study, dimension lumbers used in the actual construction sites were used to make header specimens. The used species was spruce-pine-fir (S-P-F) imported from Canada and No. 1 and 2 mixed (No. 2 and better) grade lumbers were selected. Sizes of the dimension lumbers used were nominal 2×6 (actual 38×140mm), 2×8 (actual 38×184mm), 2×10 (actual 38×235mm) and 2×12 (actual 38×286mm).

Connections between members were made by using nail guns with 12d (diameter 3.3mm, length 83mm) box nails which were not galvanized, not threaded and having smooth surface.

Box beam specimens for headers were constructed as shown in Figure 1 in which four lumbers were arranged as the shape of a box and jointed by nails. The shape of box beams and the method to make them are almost same as those generally applied in the actual timber construction sites. In box beams, because the sizes of web members and position and spacing of nails are very important factors determining their strength properties, positions of nails were exactly marked by using a chalk and nails were driven at the marked position by using nail gun. To minimize splitting of the ends of lumber which may be caused by nailing, the end distance for the nails driven at both ends of lumbers was set to 50mm. The spacing between nails was set to 100mm, 200mm and 300mm to evaluate the effect of nail spacing on the bending performance of box beams. Nail spacing was kept uniform along the whole length of a member.

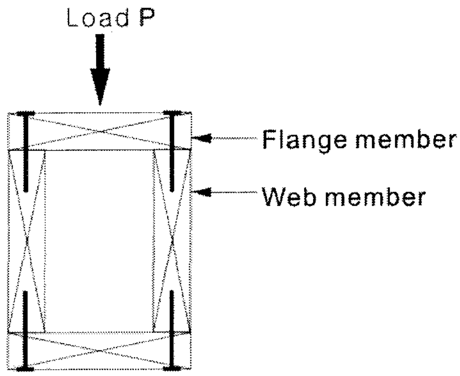


Fig.1. Manufacturing method of box beams for headers.

To evaluate the effect of the size of web members on the bending performance of box beams, each of nominal 2×6 (actual 38×140mm), 2×8 (actual 38×184mm), 2×10 (actual 38×235mm) and 2×12 (actual 38×286mm) members was used as web member. To evaluate the effect of the span on the bending performance of box beams, specimens having span lengths of 1,800mm, 2,400mm and 3,600mm were used. For all the specimens used in this study, nominal 2×6 (actual 38×140mm) members were used as top and bottom flange members and the composition and sizes of box beam specimens used in this study are given in Table 1.

Bending tests for the box beams was performed by applying the same loads to the third points of the specimens as given in KS F 2150. To measure deflection of the specimens under loads, LVDT was attached at the bottom of the central part of the specimens. LVDT was detached from the specimen after temporarily stopping the testing machine when the load level approached around 60% of the estimated maximum load and the sound indicating internal fracture of the specimens became audible, and the test till to the complete failure of the specimen occurred.

Table 1. Composition and dimensions of box beam specimens

Symbol	Dimension of web member	Span(mm)	Nail spacing(mm)
A1	2×8	2,400	100
A2	2×10	2,400	
A3	2×12	2,400	
A4	2×8	3,600	
A5	2×10	3,600	
A6	2×12	3,600	
B1	2×6	1,800	200
B2	2×8	1,800	
B3	2×10	1,800	
B4	2×12	1,800	
B5	2×6	2,400	
B6	2×8	2,400	
B7	2×10	2,400	
B8	2×12	2,400	
C1	2×8	2,400	300
C2	2×10	2,400	
C3	2×12	2,400	
C4	2×8	3,600	
C5	2×10	3,600	
C6	2×12	3,600	

The loading speed was controlled so that the maximum load can be reached in 5 minutes after starting the test. Load and deformation were measured during the test and plotted to produce load-deformation diagrams. MOE values were calculated by using equation (1) from the initial linear part of load-deformation diagrams and the maximum loads were used to calculate MOR by using equation (2).

$$MOE = \frac{P_e L^3}{4.7\Delta_e b h^3} \qquad (1)$$

$$MOR = \frac{P_{max} L}{b h^2} \qquad (2)$$

Where, P_e = load at the proportional limit (N)

L = span (mm)

Δ_e = deflection at the proportional limit (mm)

b = width of box beam (mm)

h = height of box beam (mm)
P_{max} = the maximum load (N)

The exact criterion to determine the allowable bending stress of box beams is not clear. Therefore, the allowable bending stress was set to the stress at 10mm deflection. This deflection limit was determined y considering the fact that there is still 15mm allowance between the bottom of headers and the top of doors and windows even after 10mm deflection is developed in headers because there is generally 25mm space between the bottom surface of header and the top surface of doors and windows. Span tables were produced for various cases of using box beam headers based on the allowable bending stresses obtained.

RESULTS AND DISCUSSION

MOE, MOR and allowable bending stress

MOE was calculated from the loads(P_{10} and P_{40}) and deflections(Δ_{10} and Δ_{40}) corresponding to around 10% and 40% of the maximum load which can be obtained from load-deflection diagrams produced from bending tests of box beams, and MOR was calculated from the maximum loads. In the actual wood construction, there is a spacing of 25mm between the bottom surface of header and the top surface of window. Therefore, it was considered to allow a deflection of 10mm for headers because there was still 15mm of allowance after the header deflected 10mm. The allowable bending stresses of box beam headers were determined as the stresses developed in the box beams in accordance with a deflection of 10mm.

Table 2. MOE, MOR and allowable bending stresses for box beam specimens

Symbol	MOE (N/mm^2)	MOR (N/mm^2)	Allowable bending stress (N/mm^2)
A1	3,744	22.8	9.8
A2	4,094	21.2	9.5
A3	3,855	19.7	9.6
A4	3,776	21.3	8.5
A5	4,008	20.2	8.3
A6	3,992	19.8	8.2
B1	3,860	18.2	7.3
B2	3,887	18.1	7.7
B3	3,740	17.7	7.0
B4	4,020	17.2	6.7
B5	3,954	19.3	7.4
B6	3,674	19.2	7.4
B7	3,716	19.3	7.0
B8	3,578	18.6	6.9
C1	3,869	16.3	7.2
C2	3,408	15.8	7.5
C3	3,317	16.0	6.9
C4	3,451	15.3	6.5
C5	3,256	15.3	6.4
C6	3,001	14.9	6.1

MOE, MOR and the allowable bending stresses obtained from the bending tests of box beam specimens are given as Table 2. In Table 2, MOE and MOR are the averages of the test results for 5 specimens and the allowable bending stresses were obtained as the 5% percentile calculated by equation (3) assuming normal distribution of test results.

$$F_{b,allow} = \overline{F}_{b,10} - 1,645s \qquad \text{---(3)}$$

Where, $F_{b,allow}$ = allowable bending stress (N/mm^2)
$\overline{F}_{b,10}$ = Average of the bending stresses at 10mm of deflection (N/mm^2)
s = standard deviation (N/mm^2)

1) Effects of nail spacing on the bending performance of box beams

When the nail spacing were set to 100mm, 200mm and 300mm, the allowable bending stress decreased in accordance with as shown in Figure 2. MOE was not affected by nail spacing but MOR decreased in accordance with nail spacing increased.

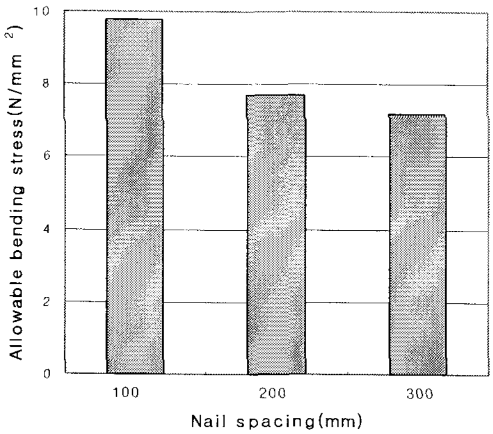


Fig.2. Change of allowable bending stresses of box beams in accordance with nail spacing (Web member dimension: 2×8 (38mm×184mm), Span: 2,400mm).

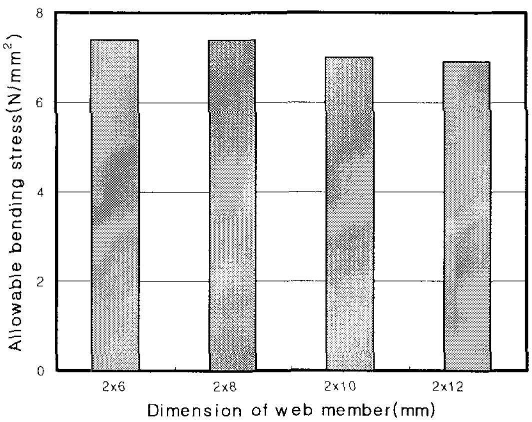


Fig.3. Effect of dimension of web member on allowable bending stresses of box beams (Span: 3,600mm, Nail spacing: 200mm).

2) Effects of the dimension of web member on the bending performance of box beams

Figure 3 shows the effect of the dimension of web members on the allowable bending stresses of box beams. Even though MOE, MOR and the allowable bending stress showed a tendency to increase as nail the dimension of web member increased, the difference was not significant.

3) Effects of span on the bending performance of box beams

MOE, MOR and the allowable bending stress did not vary so much in accordance with the conditions of specimens including span, nail spacing and member size as shown in Table 2.

Table 3. Applied loads in accordance with conditions of installation for headers (Unit: kN/m)

Location	Loading condition	Ground snow load ([1]) (kN/m^2)					
		0.5			1.0		
		Width of building(m)					
		6	8	10	6	8	10
Exterior walls	a	6.6	7.3	8.0	8.1	8.8	9.5
	b	13.4	15.8	18.3	14.9	17.3	19.8
	c	18.6	22.8	27.0	19.6	24.3	28.5
	d	20.1	24.3	28.5	21.1	25.8	30.0
	e	30.6	38.3	46.0	32.1	39.8	47.5

		Width of building(m)		
		6	8	10
Interior walls	f	10.5	14.0	17.5
	g	21.7	28.7	35.7

NOTE ([1]) Ground snow load is a terminology used in the Building Code meaning the snow load applied to the horizontal ground level. In accordance with KBC (Korea Building Code-Structural) 2005, snow loads of 0.5kN and 1.0kN can be applied to most area of our country except east sea side and island areas.

Span tables for box beam headers

In Korea Building Code-Structural 2005 (KBC 2005), span tables for headers used in the exterior walls are given as five tables corresponding to the following cases:

(a) Installing in the single story building(supporting loads transmitted from only roof and ceiling)

(b) Installing in the ground story of two story building having interior bearing wall at center of the ground story (supporting loads transmitted from roof, ceiling and second story wall, and 1/4 of the second floor loads)

(c) Installing in the ground story of two story building not having interior bearing wall(supporting loads transmitted from roof, ceiling, and the second story wall, and 1/2 of the second floor loads)

(d) Installing in the ground story of three story building having interior bearing walls at center of the ground and second stories (supporting loads transmitted from roof, ceiling, and the second and third story walls, and 1/4 of the second and third floor loads)

(e) Installing in the ground story of three story building not having interior bearing wall(supporting loads transmitted from roof, ceiling, and the second and third walls, and 1/2 of the second and third floor loads)

Span tables for headers used in the interior walls are given as two tables corresponding to the following cases:

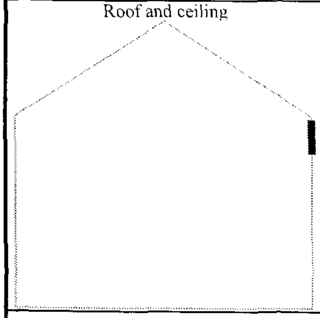
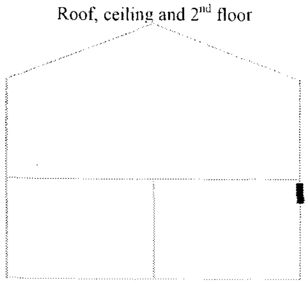
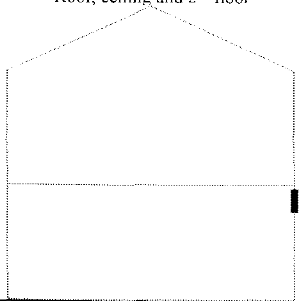
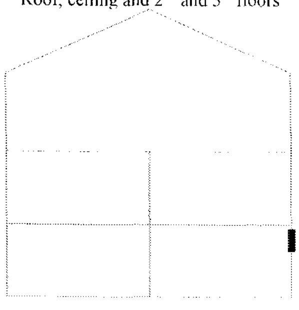
(a) Installing in the bearing of the ground story of two story building(supporting 1/2 of the second floor loads)

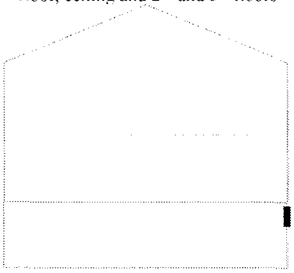
(b) Installing in the bearing of the ground story of three story building(supporting the load of the interior wall of the second story, and 1/2 of the second and third floor loads)

Headers installed in the exterior walls must support the snow loads in addition to dead loads of roof, ceiling, exterior wall and floor, and roof and floor live loads. Headers installed in the interior walls must support dead loads of floor and interior wall, and floor live loads.

For headers installed in the exterior walls under the five conditions given above, magnitudes of load per unit length of header were calculated as given in Table 3 for each case of building width of 6m, 8m and 10m and snow loads of $0.5kN/m^2$ and $1.0kN/m^2$. For headers installed in the interior walls under the two conditions given above, magnitudes of load per unit length of header were calculated and also given in Table 3 for each case of building width of 6m, 8m and 10m.

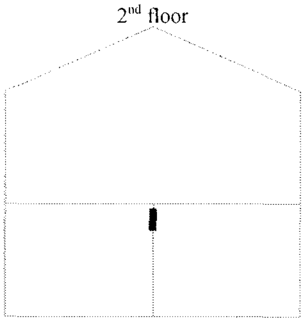
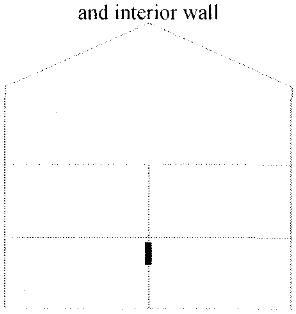
Table 4. Span table for box beam headers used in exterior bearing walls ([1])

Support condition	Dimension of web member (mm)	Nail spacing (mm)	Ground snow load ([1]) (kN/m^2)					
			0.5			1.0		
			Width of building (m)					
			6	8	10	6	8	10
Roof and ceiling 	38x140	100	2.61	2.48	2.37	2.36	2.26	2.18
	38x185		3.06	2.91	2.78	2.76	2.65	2.55
	38x235		3.55	3.37	3.22	3.20	3.07	2.96
	38x286		4.02	3.82	3.65	3.63	3.48	3.35
	38x140	200	2.29	2.17	2.08	2.06	1.98	1.91
	38x185		2.66	2.53	2.41	2.40	2.30	2.21
	38x235		3.05	2.90	2.77	2.75	2.64	2.54
	38x286		3.42	3.25	3.10	3.08	2.96	2.85
	38x140	300	2.24	2.13	2.03	2.02	1.94	1.87
	38x185		2.58	2.46	2.35	2.33	2.24	2.15
	38x235		2.94	2.79	2.67	2.65	2.55	2.45
	38x286		3.27	3.11	2.97	2.95	2.83	2.72
Roof, ceiling and 2nd floor 	38x140	100	1.83	1.69	1.57	1.74	1.61	1.51
	38x185		2.15	1.98	1.84	2.04	1.89	1.77
	38x235		2.49	2.29	2.14	2.36	2.19	2.05
	38x286		2.83	2.60	2.42	2.68	2.48	2.32
	38x140	200	1.61	1.48	1.38	1.52	1.41	1.32
	38x185		1.87	1.72	1.60	1.77	1.64	1.54
	38x235		2.14	1.97	1.83	2.03	1.88	1.76
	38x286		2.40	2.21	2.06	2.28	2.11	1.97
	38x140	300	1.57	1.45	1.35	1.49	1.38	1.29
	38x185		1.82	1.67	1.56	1.72	1.60	1.49
	38x235		2.07	1.90	1.77	1.96	1.82	1.70
	38x286		2.30	2.11	1.97	2.18	2.02	1.89
Roof, ceiling and 2nd floor 	38x140	100	1.55	1.40	1.29	1.51	1.36	1.26
	38x185		1.82	1.65	1.51	1.78	1.59	1.47
	38x235		2.11	1.91	1.75	2.06	1.85	1.71
	38x286		2.40	2.16	1.99	2.33	2.10	1.94
	38x140	200	1.36	1.23	1.13	1.33	1.19	1.10
	38x185		1.58	1.43	1.31	1.54	1.38	1.28
	38x235		1.81	1.64	1.51	1.77	1.59	1.47
	38x286		2.03	1.84	1.69	1.98	1.78	1.64
	38x140	300	1.33	1.20	1.11	1.30	1.17	1.08
	38x185		1.54	1.39	1.28	1.50	1.35	1.24
	38x235		1.75	1.58	1.45	1.71	1.53	1.41
	38x286		1.95	1.76	1.61	1.90	1.70	1.57
Roof, ceiling and 2nd and 3rd floors 	38x140	100	1.50	1.36	1.26	1.46	1.32	1.22
	38x185		1.75	1.59	1.47	1.71	1.55	1.44
	38x235		2.03	1.85	1.71	1.98	1.79	1.66
	38x286		2.30	2.10	1.94	2.25	2.03	1.89
	38x140	200	1.31	1.19	1.10	1.28	1.16	1.07
	38x185		1.52	1.38	1.28	1.49	1.34	1.25
	38x235		1.75	1.59	1.47	1.70	1.54	1.43
	38x286		1.96	1.78	1.64	1.91	1.73	1.60
	38x140	300	1.28	1.17	1.08	1.25	1.13	1.05
	38x185		1.48	1.35	1.24	1.44	1.31	1.21
	38x235		1.68	1.53	1.41	1.64	1.49	1.38
	38x286		1.87	1.70	1.57	1.83	1.65	1.53

Roof, ceiling and 2nd and 3rd floors 	38x140	100	1.21	1.08	0.99	1.18	1.06	0.97
	38x185		1.42	1.27	1.16	1.39	1.25	1.14
	38x235		1.65	1.47	1.34	1.61	1.44	1.32
	38x286		1.87	1.67	1.52	1.82	1.64	1.50
	38x140	200	1.06	0.95	0.87	1.04	0.93	0.85
	38x185		1.23	1.10	1.01	1.20	1.08	0.99
	38x235		1.41	1.26	1.15	1.38	1.24	1.14
	38x286		1.59	1.42	1.29	1.55	1.39	1.27
	38x140	300	1.04	0.93	0.85	1.02	0.91	0.83
	38x185		1.20	1.07	0.98	1.17	1.05	0.96
	38x235		1.36	1.22	1.11	1.33	1.20	1.10
	38x286		1.52	1.36	1.24	1.48	1.33	1.22

NOTE ([1]) Dead loads, live loads and snow loads were considered to make this span table.

Table 5. Span table for box beam headers used in interior bearing walls

Support condition	Dimension of web member (mm)	Nail spacing (mm)	Width of building (m)		
			6	8	10
2nd floor 	38x140	100	1.78	1.54	1.38
	38x185		2.12	1.84	1.64
	38x235		2.50	2.16	1.93
	38x286		2.87	2.48	2.22
	38x140	200	1.56	1.35	1.21
	38x185		1.84	1.60	1.43
	38x235		2.14	1.86	1.66
	38x286		2.43	2.11	1.89
	38x140	300	1.53	1.32	1.18
	38x185		1.79	1.55	1.39
	38x235		2.07	1.79	1.60
	38x286		2.33	2.02	1.80
2nd and 3rd floors and interior wall 	38x140	100	1.24	1.08	0.96
	38x185		1.48	1.28	1.15
	38x235		1.74	1.51	1.35
	38x286		1.99	1.73	1.55
	38x140	200	1.08	0.94	0.85
	38x185		1.28	1.11	1.00
	38x235		1.49	1.30	1.16
	38x286		1.69	1.47	1.32
	38x140	300	1.06	0.92	0.83
	38x185		1.25	1.08	0.97
	38x235		1.44	1.25	1.12
	38x286		1.62	1.41	1.26

NOTE ([1]) Dead loads, live loads and snow loads were considered to make this span table.

Using the allowable bending stresses given in Table 2 under the applied load given in Table 3, the allowable spans of box beams can be expressed as equation (5) by applying principles of structural mechanics.

$$\sigma_{allow} = \frac{wL^2}{8S} \qquad (4)$$

$$L = \sqrt{\frac{8S\sigma_{allow}}{w}} = \sqrt{\frac{8bh^2\sigma_{allow}}{6w}} \qquad (5)$$

Where, σ_{allow} = allowable bending stress (kN/m^2)
w = load applied to header (kN/m)
L = span of header (m)
S = section modulus of header (m^3)
b = width of header (m)
h = height of header (m)

Span tables for headers installed in the exterior and interior walls calculated by equation (5) are given in Table 4 and Table 5, respectively. In Table 5, spans were calculated based on the box beam headers having 2×4(38×89mm) top and bottom flange members.

CONCLUSIONS

Box beams used as window headers in the light-frame wood construction were tested under bending loads. From the test results, span tables for the box beam headers having 2×6 (38×140mm) (exterior wall header) or 2×4 (38×89mm) (interior header) top and bottom flange members, and 2×6(38×140mm), 2×8 (38×184mm), 2×10 (38×235mm) and 2×12 (38×286mm) web members were obtained. Span tables were obtained under five loading conditions corresponding to five header positions in the exterior walls and two loading conditions corresponding to two header positions in the interior walls. By applying these span tables, anyone can easily design the box beam headers installed on top of the window and door openings without complex structural calculations.

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