Replacement of Line Loads acting on slabs to equivalent uniformly Distributed Loads

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Abstract

This study aims to derive a general relation between line loads that acting on two-way slab system and the equivalent uniformly distributed loads. This relation will be so useful to structural designer that are used to working with a uniformly distributed load and enable them to use the traditional methods for analysis of two-way systems (e.g. Direct Design Method).

Two types of slab systems, Slab System with Beams and Flat Slab Systems, have been considered in this study to include the effect of aspect ratio and type of slab on the proposed relation. Five aspect ratios, l_2/l_1 of 0.5, 0.75, 1.0, 1.5 and 2.0, have been considered for both types of two-way systems.

All necessary finite element analyses have been executed with **SAFE Software.** Data obtained from the F. E. analyses have been used in a statistical analysis using **Statistic Software** to derive the relation based on a Linear Regression Analysis.

Keywords: Line Loads, Equivalent Uniformly Distributed Loads, Two-way Slabs, Flat Slabs, SAFE, Finite Element Analysis, Statistical Analysis, Linear Regression Analysis.

أستبدال الأحمال الخطية المؤثرة على البلاطات الى احمال مكافئة موزعة بأنتظام

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الخلاصـــــــة:

تقدم هذة الدراسة بحثا تحليليا يخص تحويل الاحمال الخطية المسلطة على السقوف الخرسانية كأحمال الجدران الى أحمال منتشرة وموزعة بأنتظام مكافئة للأحمال الاصلية ومؤثرة على كافة مساحة السقف وذلك لتسهيل عملية التصميم لهذه السقوف بطرق التصميم السائدة والمعدة بالاساس للأحمال الموزعة بأنتظام كطرق التصميم الموجودة في المدونة الأمريكية (مثل طريقة التصميم المباشر).

تم أخذ نوعين من أكثر أنواع السقوف أنتشارا (السقوف المسندة على أعتاب خرسانية والسقوف المستوية) حيث تم دراسة أهم العوامل المؤثرة على العلاقة بين الحمل الخطي والحمل المنتشر المكافيء له ومن أهمها نسبة طول الفضاء الى طول الفضاء العمودي عليه وكذلك نسبة جساءة العتبب الى جساءة السقف (في النوع الاول فقط) حيث تم أخذ خمسة نسب من نسبة طول الفضاء على طول الفضاء العمودي عليه (0.5، 0.75، 1.0,1.5 و 2.0) لكل نوع منهما.

تم تسليط أحمال خطية مرة وموزعة بأنتظام مرة أخرى على هذه السقوف وحللت بطريقة العناصر المحددة وبأستخدام برنامج: (SAFE Software V. 12).

ولايجاد العلاقة بين الحمل الخطي والحمل الموزع بأنتظام و المكافيء له تم الاعتماد على طريقة تحليل الأنحدارحيث تم ادخال البيانات المستحصلة من تحليل الانظمة أعلاه الى البرنامج الاحصائي: (STATISTIC Software)

الكلمات الرئيسية: الأحمال الخطية، الأحمال المكافئة الموزعة بأنتظام ، بلاطات ثنائية، بلاطات مستوية،تحليل السقوف بطريقة العناصر المحددة، التحليل بالعناصر المحددة، التحليل الأحصائي،تحليل الأرتباط الخطي.

INTRODUCTION

Line loads, as may be applied by walls, are a special case of loads acting on small areas. It has apparently been customary to take the weight of interior walls into account by adding an addition uniformly distributed loads of 1.44 kN/m^2 to the dead load of the slab.[1].

Woodring [2] studied the effects of an arbitrary length placed concrete block wall weighing 4.43 kN/m (304 lb/ft) and extending to an arbitrary length. The wall was considered to have zero stiffness and hence to apply a uniform line load to the slab regardless of the slab deflection. Considering a single wall, the 1.44 kN/m^2 (30 psf) allowance was more adequate than for any length and placement of the wall as far as the negative moments in beamless slabs were concerned. However, if the wall was placed at midspan and especially if it extends across several panels, the 1.44 kN/m^2 (30 psf) allowance was inadequate for positive moments. When the wall extended across the full width of one panel, the required allowance to properly compensate for the effects on midspan moments acting in the direction perpendicular to the wall varied from 3.2 kN/m^2 when l_1 = 6.1m to 2.1 kN/m^2 when l_1 = 9.15m. If the wall extended across more than one panel, the required equivalent loads would be slightly larger. Thus, it may be desirable, if inconvenient; to design the positive–moment sections with one equivalent load and the negative-moment sections for another lower equivalent load. Then the equivalent uniformly distributed load can be computed by using the following equation [1]:

$$w^* = \frac{\overline{w}C}{L} \qquad (1)$$

Where:

: is the equivalent uniformly distributed load per unit width.

: is the weight of wall per unit length.

: Span of square panel.

C: concentration coefficient, where a positive number indicates moments with the same sign as are caused by distributed loads.

According to Syrian Code[3], the line loads light in weight can be replaced by an equivalent uniformly distributed load when the line loads on slab systems equal to or less than 1.5 kN/m^2 on the area under wall and as shown in **Fig. 1**.

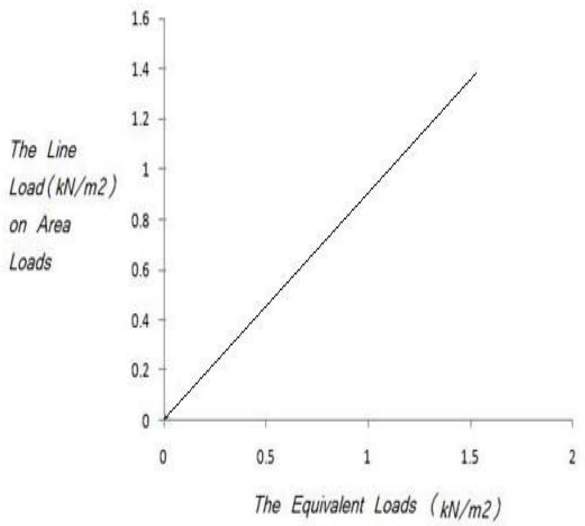

Fig. 1
Equivalent Uniform Loads to Line Loads [3]

Also when the live load applied on slab systems is greater than a 6 kN/m^2 the effect of the line loads can be neglected [(3)].

According to Egyptian Code, when the design live loads is greater than or equal to 5.0 kN/m^2 and the line loads equal to or less than 1.0 kN/m^2, line load effects can be neglected [(4)].

According to the International Building Code, in the office and other buildings where partition locations are subjected to change, provision for partition weight shall be made, whether or not partitions are shown on the construction documents, unless the specified live load exceeds 3.83 kN/m^2 (80 psf). Such the partition load shall not be less than a uniformly distributed live load of 0.96 kN/m^2 (20 psf) (according to **IBC 2003)**[(5)] or 0.74 kN/m^2 (15 psf) (according to **IBC 2006)** [(6)]**.**

EQUIVALENT UNIFORM LOAD:

As discussed in the previous section, most of current methods for estimating the equivalent uniformly distributed load recommend a constant value of the equivalent uniformly distributed load that does not depend neither on the intensity of the original line load nor on system parameters (existence of beams, stiffness of beams, and panel aspect ratio). The main goal of this study is to develop a more rigorous relation that includes these effects into account. This has been started with finite element analyses of the two-way systems under a unit line loads and unit uniformly distributed loads. These finite element results had been used in a linear regression analysis to obtain the required general relation.

FINITE ELEMENT ANALYSES:

Finite element analyses (executed by **SAFE Software**) for systems with following properties:

1. A Concrete slab of 0.2 m thick.
2. Concrete beams (for slab with beams) with dimensions of 0.4 m by 0.6 m and a relative flexural stiffnesses “ ” greater than two ($\alpha \frac{l_2}{l_1}$).
3. All concrete columns have dimensions of 0.4 m by 0.4 m.
4. A line load of (1) and uniform distribution load (1 kN/m^2).
5. A square finite element mesh with dimensions of 20 cm by 20 cm.

Five different aspect ratios have been considered in each case study, namely 0.5, 0.75, 1.0, 1.5, and 2.0. Then the lengths will be l_2 is 4, 3, 5, 6, and 8 and l_1 is 8, 4, 5, 4, and 4.

For each aspect ratio, the system has been subjected to the following two load cases:

First Load Case: This load case intends to simulate the floor systems that subjected to quasi symmetrical line loads. Then in this load case all center lines in the direction under consideration have been subjected to line loads and as shown in **Fig. 2** for slab with beams and in **Fig. 3** for flat slab systems.

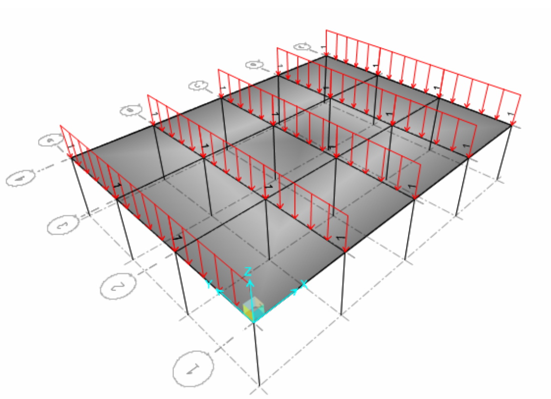

Fig. 2:
Slab with beams subjected to unit line load (kN/m).

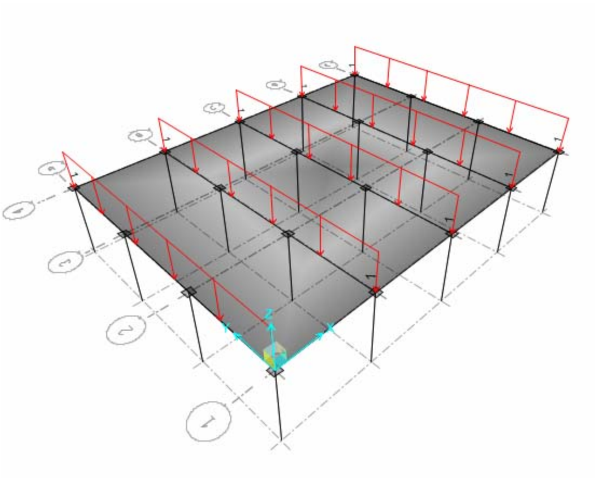

Fig. 3:
Flat slab subjected to unit line load (kN/m).

In the second Load Case the re-analysis of these systems under a uniformly distributed load with unit load value as shown in **Fig. 4** for slab with beams and **Fig. 5** for flat slab systems to obtain the data in **Table 1** for slab with beams and then, to obtain **Table 2** for flat plat slabs.

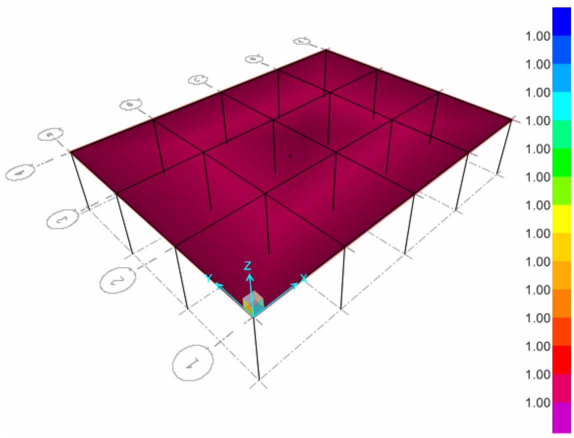

Fig. 4:

Slab with beams subjected to unit uniformly Distribution load (kN/m^2).

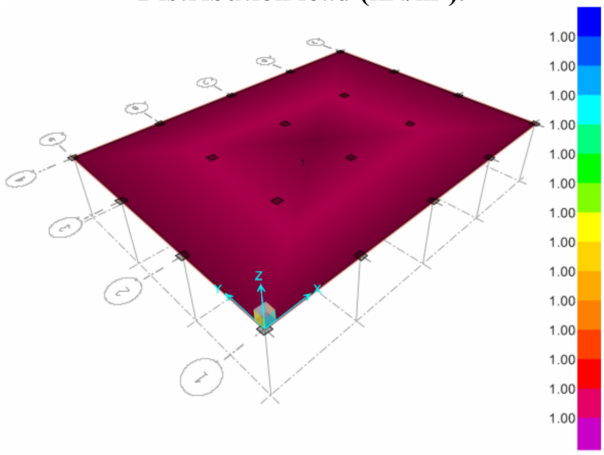

Fig. 5:
Flat slab subjected to unit uniformly Distribution load (kN/m^2).

In these Tables, the ratio W_{UDL}/W_{Line} Load has been computed as follows:

1. Based on linearity of structure:

$$M_{Due\ to\ Line\ Load} = M_{Unit\ Line\ Load} \times W_{Line}$$
$$M_{Due\ to\ UDL} = M_{Due\ to\ Unit\ UDL} \times W_{UDL}$$

2. Based on definition of the equivalent uniformly distributed load:

$$\because M_{Due\ to\ UDL} = M_{Due\ to\ Line\ Load}$$
$$\therefore M_{Unit\ UDL} \times W_{UDL} = M_{Unit\ Line\ Load} \times W_{Line}$$
$$\therefore \frac{W_{UDL}}{W_{Line}} = \frac{M_{Due\ to\ Unit\ Line\ Load}}{M_{Due\ to\ Unit\ UDL}}$$

Table 1: Comparison of Moment due to Unit Line Load and Corresponding Unit Uniformly Distributed Load (UDL) for Two-way Slabs with Beams (see Fig. 2 and Fig. 4):

Aspect Ratio	α	Mv	Moments Due to a Unit Line Load $(kN \times m/m)$			Moments Due to Unit UDL $(kN \times m/m)$			Average $W_{UDL}/W_{Line} = M_{Line}/M_{UDL}$
			M_{beam}	M_{cs}	M_{ms}	M_{beam}	M_{cs}	M_{ms}	
0.5	**4.342**	-Mv	4.24	0.511	0.418	16.19	2.229	2.365	0.248700924
		+Mv	1.683	0.181	0.159	6.595	0.527	0.905	0.252024418
0.75	**5.787**	-Mv	0.877	0.1194	0.0814	2.3515	0.418	0.465	0.333219972
		+Mv	0.4579	0.0484	0.0345	1.2341	0.0954	0.2793	0.336151169
1.0	**3.742**	-Mv	1.451	0.250	0.133	5.676	1.513	1.932	0.201074444
		+Mv	0.664	0.100	0.043	2.473	0.338	1.108	0.205919878
1.5	**2.893**	-Mv	0.849	0.1384	0.0852	3.1297	0.8926	2.3783	0.16757804
		+Mv	0.4625	0.0597	0.0232	1.487	0.1276	1.606	0.169347327
2.0	**2.170**	-Mv	0.845	0.138	0.083	3.405	1.083	3.902	0.127056019
		+Mv	0.469	0.061	0.022	1.672	0.043	2.710	0.124745763

Where:

M_{cs}: Moment in column strip

M_{ms}: Moment in middle strip

Table 2: Comparison of Moment due to Unit Line Load and Corresponding Unit Uniformly Distributed Load (UDL) for Flat Plate Slab (see Fig. 3 and Fig 5):

Aspect Ratio	Mv	Moments Due to a Unit Line Load $(kN \times m/m)$		Moments Due to Unit UDL $(kN \times m/m)$		Average $W_{UDL}/W_{Line} = M_{Line}/M_{UDL}$
		M_{cs}	M_{ms}	M_{cs}	M_{ms}	
05	-Mv	2.9947	1.7753	12.541	6.986	0.244277155
	+Mv	1.1853	1.0940	4.743	4.703	0.2412979040
0.75	-Mv	0.7746	0.2627	2.3608	0.9114	0.3170038510
	+Mv	0.3022	0.2068	0.8314	0.7435	0.323195123
1.0	-Mv	1.380	0.430	7.00	2.027	0.2005095820
	+Mv	0.553	0.257	2.338	1.716	.199802664
1.5	-Mv	0.839	0.2791	5.3146	1.2997	0.169042831
	+Mv	0.347	0.1514	1.3850	1.5686	0.168743229
2.0	-Mv	0.840	0.278	7.432	1.446	0.125929263
	+Mv	0.352	0.149	1.392	2.446	0.130536738

Where:

+Mv: The positive moment

-Mv: The negative moment

REGRESSION ANALYSIS

Multiple regressions analysis have been executed to derive required relationship based on finite element results that summarized in Table 1 and Table 2. This has been executed by STATISTICA Software. Using $\frac{W_{Eq.l}}{W_{Actual\,L}}$ as dependent variable and and as independent variables, linear regression relation will take the following form:

$$\frac{W_{Eq.UDL}}{W_{Actual\,Line\,Load}} = a_0 + a_1\alpha + a_2\frac{l_2}{l_1} \qquad (2)$$

where:

α is the relative ratio of the stiffness of beam to slab, is the aspect ratio.

W_{UDL}/W_{Line} is the ratio of equivalent uniformly distributed load to actual line load. , , and are regression coefficients.

Based on finite element results and statistical model that proposed in Eq. (2), one can conclude that the general relation between actual line load and the equivalent uniformly distributed will be:

$$\frac{W_{Eq.UDL}}{W_{Actual\,Line\,Load}} = 0.32193 + 0.00473\alpha - 0.10175\,\frac{l_2}{l_1} \qquad (3)$$

It is useful to note that this relation has a multiple correlation coefficients (R) equal to 0.8327334. This gives an indication that there is an actual linear proportionality between the dependent and independent variables. To assess the effect of each one of independent variables, correlation coefficient (r) has been computed as shown in **Fig. 6** and **Fig. 7 (each Fig. for both types of Slab Systems)** below:

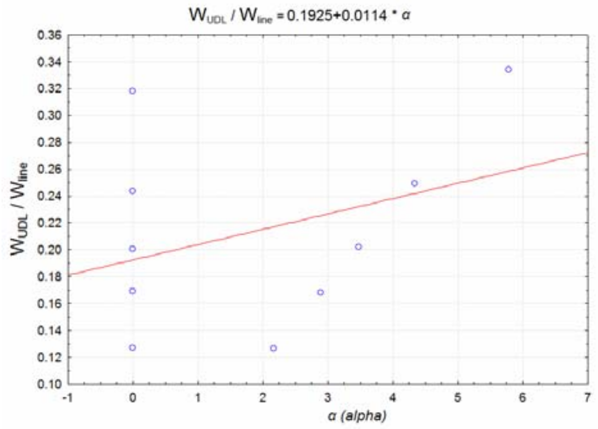

Fig. 6
Relationship Between (W_{UDL}/W_{Line}) and α.(Relative stiffness of beam to slab)

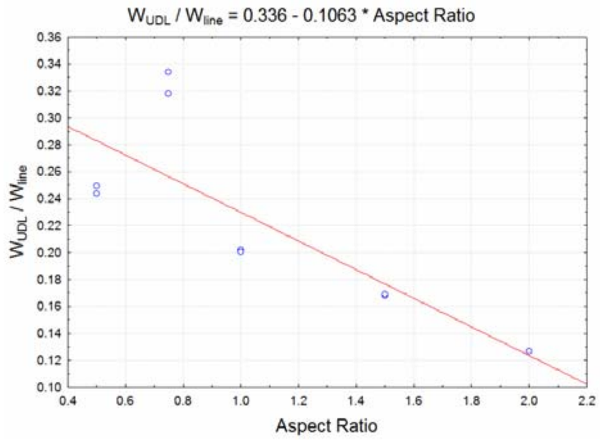

Fig. 7
Relationship Between (W_{UDL}/W_{Line}) and Aspect Ratio

CONCLUSIONS

Based on finite element analyses and regression analyses that have been executed in this study, one can conclude that an accurate estimation of the uniformly distributed load that equivalent to a known line load should include parameters related to system type and beams relative stiffness (in there is any beam in the system) in addition to the value of the line load.

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NOTATION:

l_1	Span under consideration (m)
l_2	Lateral span length (m)
$\bar{w}$	Weight of wall per unit length (kN/m).
w^*	Equivalent uniformly distributed load (kN/m^2)
, , and	Coefficients of regression
C	Concentration coefficient
L	Span of square panel (m).
R	Correlation coefficients
W_{Line}	The actual line loads (kN/m)
W_{UDL}	Equivalent uniformly distributed load (kN/m^2) for the actual line loads
α	Relative ratio of the stiffness of beam to slab
M_{cs}	Moment in column strip
M_{ms}	Moment in middle strip
+Mv	The positive moment
-Mv	The negative moment