ANALYSIS OF TWO-WAY (WAFFLE) COMPOSITE SLABS

M. Khalaf[1], A. El-Shihy, H. Shehab & S. Mustafa

[1]Civil & Arch. Eng. Dept., Fac. of Eng., Jefarah Branch, Al-Fateh University, Tripoli, Libya
E-Mail: drmagdykhalaf@yahoo.com
Structural Engineering Dept., Faculty of Engineering, Zagazig University, Zagazig, Egypt

الملخص

تطور إستخدام المنشآت المركبة بشكل مطرد خلال العقود القليلة الماضية عقب معرفة مميزات وفوائد الأسقف الخرسانية المصبوبة على ألواح الحديد المدرفلة على البارد. إلا أنه ظهرت بعض السلبيات بسبب أن البلاطات المركبة ينتقل خلالها معظم الحمل فى إتجاه واحد أساسى هو إتجاه الدرفلة بغض النظر عن كون مثل هذه البلاطات ذات إتجاه واحد أو ذات إتجاهين كما هو معروف تبعاً لنسبة طولها إلى عرضها. وهذا يؤدى إلى زيادة الحمل على الكمرات الحاملة فى أحد الإتجاهات لكل باكية وهو الإتجاه المتعامد على إتجاه الدرفلة بشكل ملحوظ عن مثيلاتها فى الإتجاه الآخر حيث تكون تقريباً غير محملة مما يعد عاملاً سلبياً من الناحية الإقتصادية. لهذا السبب وغيره تمخضت لدينا فكرة إستخدام ألواح حديدية مدرفلة فى الإتجاهين.

ولإنجاز هذه الفكرة تم إختيار النموذج الرياضى الأفضل بطريقة العناصر المحددة "Finite Elements" من بين ثلاث نماذج مقترحة وهى المسماه بنموذج الشكل الحقيقى والنموذج المكافئ والنموذج الشبكى وذلك لتمثيل البلاطات المركبة ذات الألواح الحديدية المدرفلة فى الإتجاهين ومقارنة النتائج بتلك لنفس النموذج ولكن للبلاطات المركبة العادية المعروفة ذات ألواح الحديد المدرفلة فى إتجاه واحد فقط . ونظراً لعدم توفر نتائج معملية أو تحليلية عددية أو حتى إفتراضية معتمدة على الخبرة لمثل هذا النوع الجديد المقترح من الأسقف المركبة لتقييم النتائج فقد كان من الضرورى دراسة السلوك الإنشائى للبلاطات ذات الألواح الحديدية المدرفلة فى إتجاه واحد والمعروفة جيداً مسبقاً بإستخدام النماذج الرياضية العددية المقترحة للمفاضلة فيما بينها وتقييمها بما يتوفر لدينا من دراسات ونتائج معملية لبحوث سابقة فى هذا المجال.

وبعد إختيار النموذج الأفضل أجريت دراسة مستفيضة وموسعة لإستنتاج أثر بعض العوامل الهامة على السلوك الإنشائى للنوع المقترح من الأسقف المركبة مثل نسبة طول الباكية لعرضها والشروط الهندسية المحيطة بها وعمق لوح الحديد المدرفل ونسبة طول وحدة شكل الدرفلة لعرضها وكذلك تموضعها بالنسبة لوضع باكية السقف. تم التوصل لنتائج مثيرة ومشجعة

للمضى قدماً فى هذا الإتجاه البحثى ووضعت بعض التوصيات الهامة التى تفتح البـــاب علـــى مصراعيه أمام تطوير هذا النوع الجديد المقترح من الأسقف المركبة.

ABSTRACT

For few decades and since the well–known composite slabs consisting of reinforced concrete poured on corrugated steel sheet was achieved, the use of composite structures has grown widely. However and since this type of slabs acts as a one-way slab due to the steel sheet ribs configurations, some problems have been created such as having two parallel heavily loaded beams in each panel while the other two perpendicular beams are almost unloaded; which is uneconomic.

Owing to the above reason and others, the idea of using two-way (or *waffle*) composite slabs was brought up. Carrying out such research required firstly choosing the most appropriate finite element modeling technique in representing the two-way or waffle composite slab and comparing its behavior to that of one-way. Three modeling techniques named real shape, equivalent and grillage models were tested and represented by two and three-dimensional finite element techniques to detect the best of them. Since no previous experimental, numerical or empirical results of waffle composite slab analysis were yet available to evaluate the modeling results, it was necessary to study also the behavior of the well-known one-way composite slab using the pre-mentioned modeling techniques.

After the best finite element model was selected, an extensive parametric study ; in which many influencing parameters were tested such as slab aspect ratio, slab boundary conditions, steel sheet depth, corrugation cell aspect ratio and its orientation ; was carried out in order to investigate the overall behavior of two-way composite waffle slab under different conditions.

Many encouraging and exiting results are obtained and important recommendations are stated which open the door completely for this new configuration or technique of composite slabs in design and erection of composite structures.

KEYWORDS: Composite; Structures; Corrugated; Profiled; Steel Sheet; Concrete; Slabs; Two-Way; Waffle; Grillage; Equivalent; Real.

INTRODUCTION

The two-way behavior is always preferable to that of one-way in all slab types due to its better structural behavior and economy in the cross sectional dimensions. Many researches studied experimentally and numerically the one-way behavior of composite slabs reinforced with steel sheet corrugated in one direction; Porter & Ekberg [1], Porter [2], An [3] and Khalaf et.al. [4]. However no researchers studied slabs with steel sheet corrugated in the two main orthogonal directions. In this paper a new suggested composite slab structural system named "*Waffle Composite Slab*" is presented. In addition to the expected and pre-mentioned better structural behavior of waffle composite slab, the way by which the corrugated steel sheet is formed is expected to prevent the horizontal slippage between the concrete and the steel sheet which is considered a very serious mode of failure in one-way composite slabs.

The main aim of this research is to analyze the structural behavior of the new suggested composite slab type under different conditions using the well known

Structural Analysis Program SAP2000 [5]. Indeed, this analysis requires a very careful choice of the used modeling technique to accurately simulate the waffle composite slabs. Therefore firstly, a modeling techniques evaluation of waffle composite slabs was achieved numerically using the finite element technique and compared to the previously available experimental results of one-way composite slab types to achieve the best modeling among three models named real shape, equivalent and grillage models assuming full interaction between steel sheet and overlaying concrete.

Many influencing parameters such as the waffle rectangularity, boundary conditions, depth and corrugation cell aspect ratio and corrugation type (trapezoidal and re-entrant) which were expected to affect the structural behavior of the two-ways waffle composite slabs were investigated under uniformly distributed loads.

MODELING EVALUATION

Three different finite element modelling techniques were used to model composite slabs in order to detect the best of them. Since no previous results were available to compare with, it was necessary to start with modeling the traditional one-way composite slab and compare the results with those of previous models; Porter & Ekberg [1], Porter [2] and An [3].

The corrugations of two-way (*waffle*) composite slabs may have equal or different dimensions in the two orthogonal directions; Figure (1). Since there is no steel sheet having this style of corrugation in the market yet, the standard corrugations dimensions of the one-way corrugated steel sheets available in market were considered. Then the dimensions of corrugations were changed gradually in one of the two directions to study their effect on the slab behaviour; as will be detailed later.

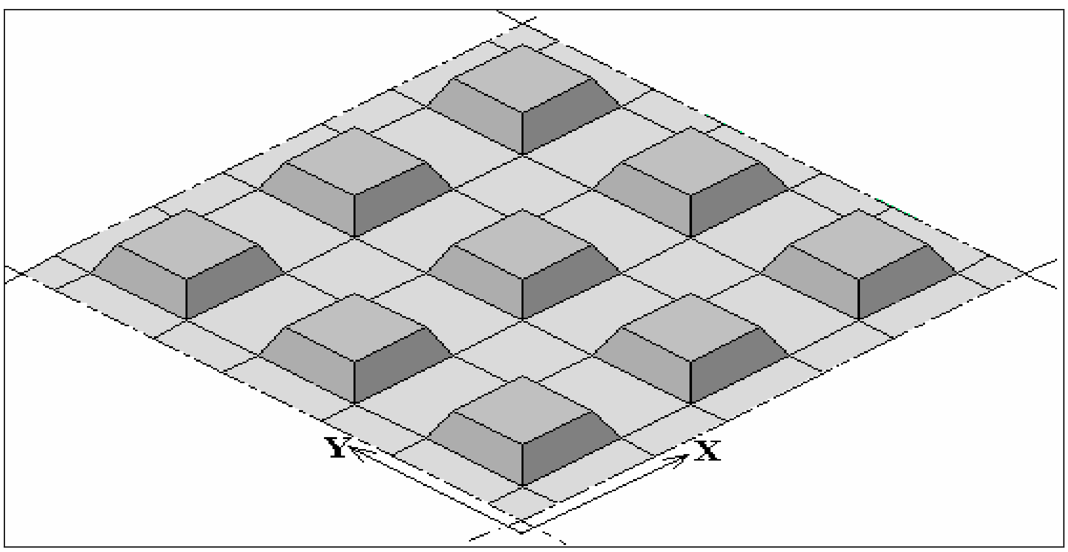


Figure 1: Suggested shape of waffle steel sheet

MODEL DIMENSIONS AND APPLIED LOADING CONFIGURATIONS

For the sake of comparison, the dimensions and the loading configurations of previously investigated models of Klaiber & Porter [6]; as shown in Figures (2 and 3); were maintained.

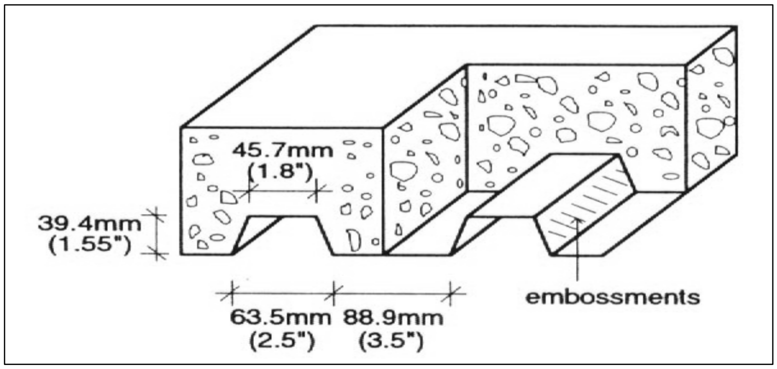


Figure 2: Cross sectional dimensions of composite slab

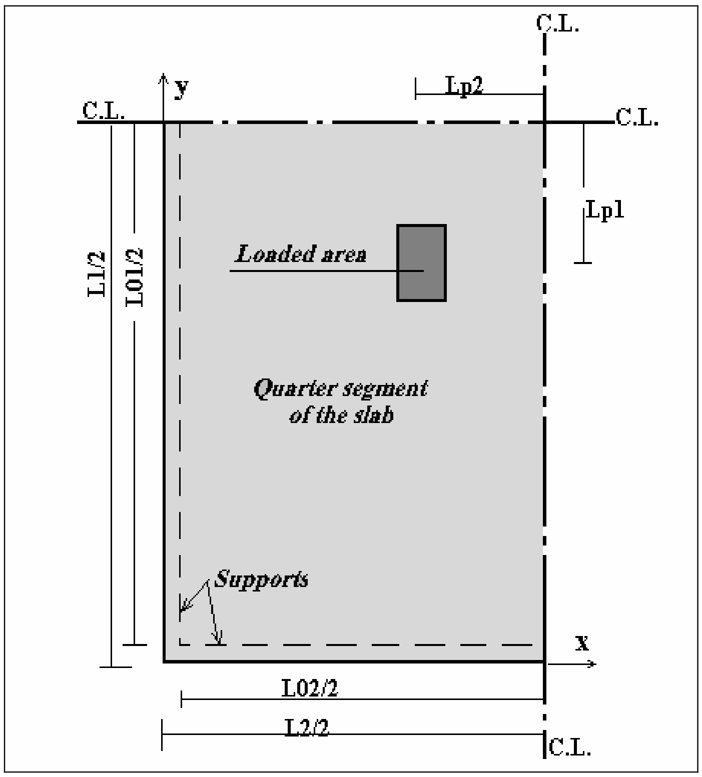


Figure 3: Slab loading and dimensions

The slab had dimensions of (3.66 × 4.88 m) (L2 × L1). For one-way slab, the steel sheet was oriented in direction of the short span. The steel sheet used had rolled embossments on the webs to provide longitudinal shear resistance at the concrete–steel sheet interface.

Four symmetrical concentrated loads were applied to ultimate capacity. This was depending on the assumption that a slab element with concentrated loads at the quarter points behaves in a similar manner to a slab element with uniform loading. The ultimate load on each loading point was 6.0 *tons*. In waffle composite slab, the steel sheet dimensions were the same in the two directions of the slab. Depending on full bond between steel sheet and concrete and linear elastic uncracked behaviour of concrete assumptions, the maximum load was obtained once the stress in any steel element reaches the yield strength or the compressive strain in concrete reaches the maximum compressive strain or if the maximum deflection of the slab reaches the allowable deflection value; European Code, ECCS [7].

THREE–DIMENSIONAL REAL SHAPE MODEL

Both one–way and waffle composite slabs were modelled using the three–dimensional finite element real modelling technique. The concrete body was divided into four layers; as shown in Figure (4).

Layers 1 & 2 were in compression zone and consequently suffering compressive stress while layers 3 & 4 were in tension zone (i.e. under neutral axis of stresses; N.A.) and neglected in analysis.

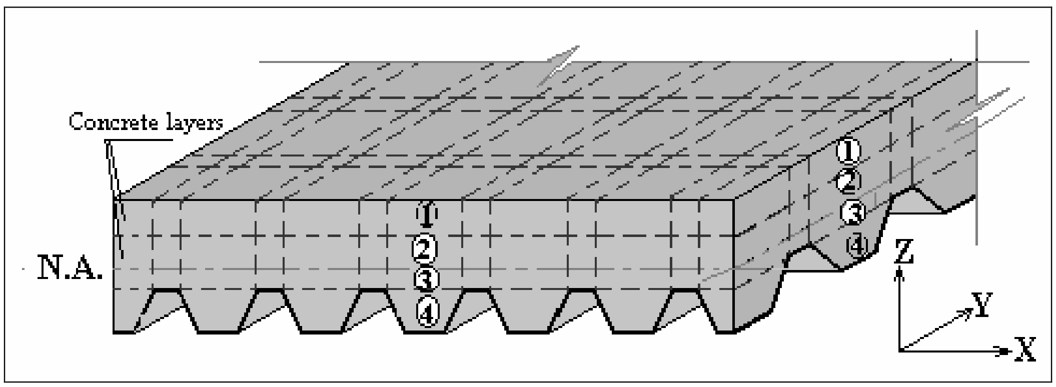


Figure 4: 3-D Real shape model of waffle composite slab

Two–Dimensional Equivalent Model

This model simulates the Beam-plate bending model introduced by Khalaf et.al. [4] as detailed in Figure (5). For *one-way composite slab*, the concrete layer was modeled as a series of two adjacent plate bending elements which had the same properties and different thickness to simulate the depth variation of concrete layer due to the steel sheet corrugation geometry. The steel-deck was modeled as beam elements in direction of the ribs "*strong direction*".

For *waffle composite slab*, the steel sheet was represented by two-node beam elements in the two orthogonal directions. The concrete was represented by a series of two adjacent plate bending elements. For one-way composite slab, it had two different thicknesses of 83.6 mm and 119.7 mm, with widths of 45.7 mm and 106.7 mm respectively. In waffle composite slab, the elements representation was slightly modified to maintain the previously used procedure; Figure (5).

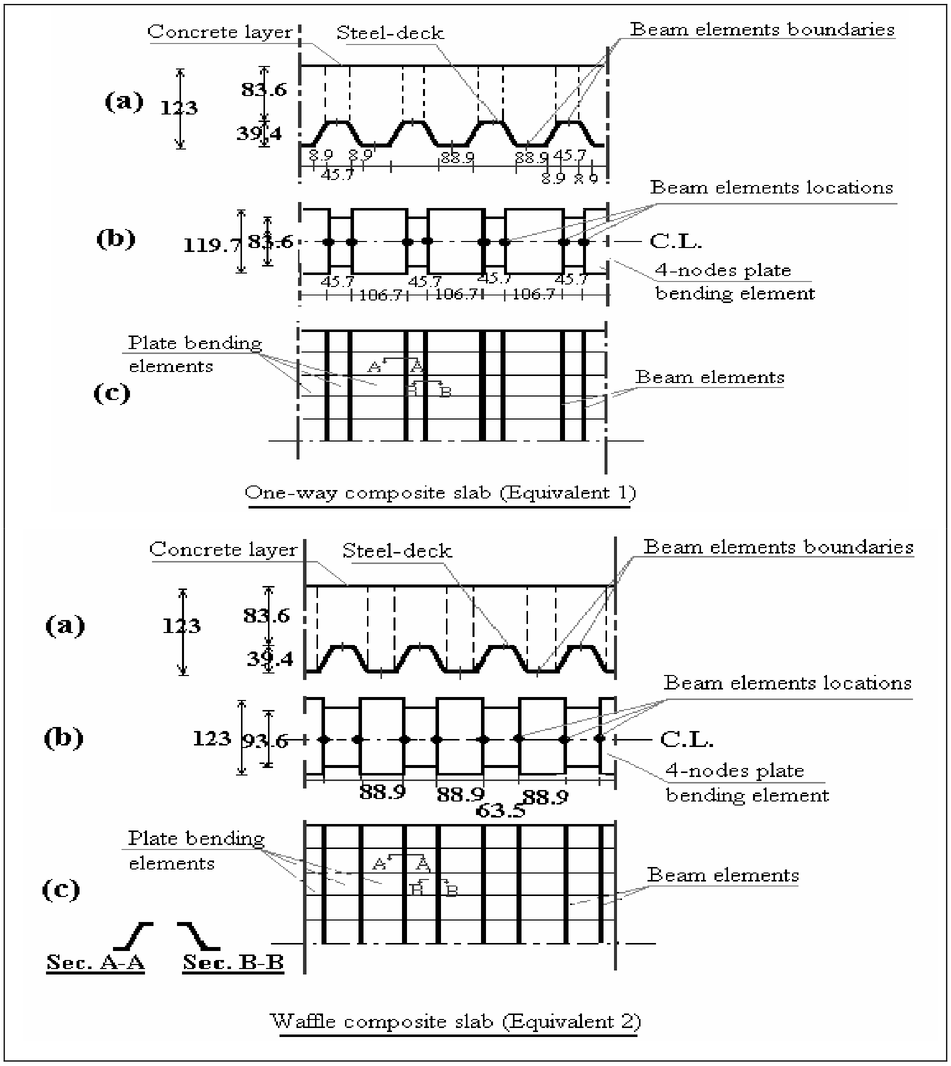


Figure 5: Two-dimensional equivalent model [4]

TWO-DIMENSIONAL GRILLAGE MODEL

Waffle composite slab was modelled using the grillage model which had grillage beams in both directions; Figure (6). They were chosen to coincide with the rib centre lines, to simplify data preparation. Each cycle of the waffle composite slab was idealized as an equivalent frame element having the same transformed area and moment of inertia of the real cross section, (*in concrete dimensions*). The remaining part of concrete over the supporting steel **I**–beam, and the supporting steel **I**-beam itself was represented as beams having the same area and moment of inertia of the real section, (*in concrete dimensions*). Figure (6) shows all sketching details of this modelling technique.

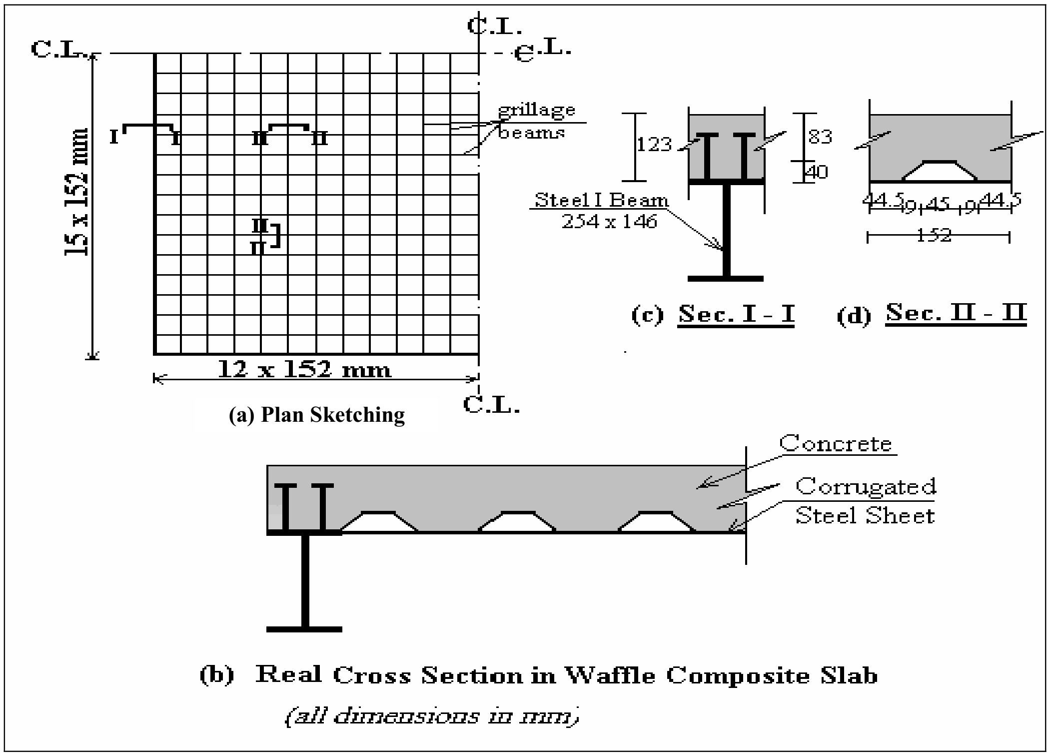


Figure 6: Two-dimensional grillage model

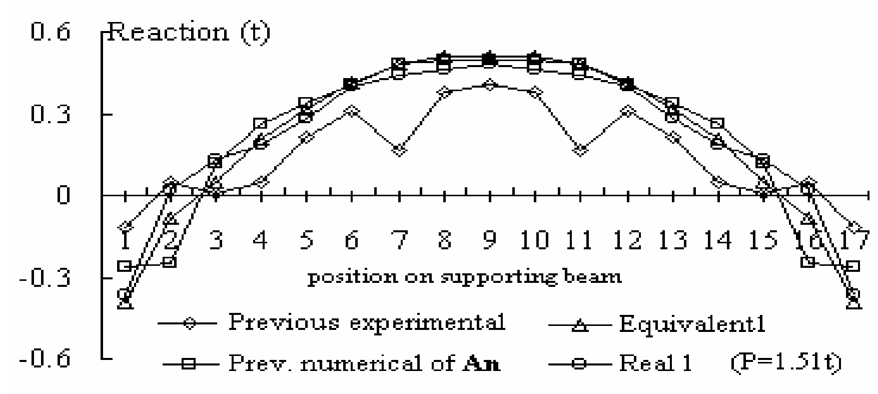
RESULTS AND DISCUSSION

Comparison between the three models is based mainly on the distribution of forces at the two orthogonal longitudinal supports. Figure (7) shows the distribution of forces in the long and the short directions for the previously mentioned experimental test of Porter and Ekberg [1], numerical of An [3], Equivalent of Khalaf et.al. [4] and Real models. Table (1) shows the total transferred load in the two directions of the compared slabs.

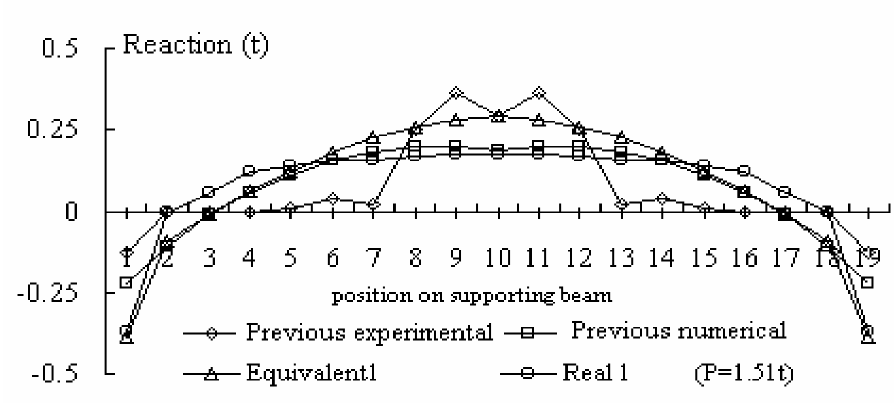
Table 1: Percentage of load transferred in each direction

P = 2.15 t (*1/3* P_u)	Main (%)	Secondary (%)
Previous experimental	71.6	28.4
Previous numerical	73.4	26.6
Real 1	73	27
Equivalent1	69.6	30.4
Real 2	63	37
Equivalent 2	61.1	38.9
Grillage	70.1	29.9

Where: P is one fourth of the applied load on the slab



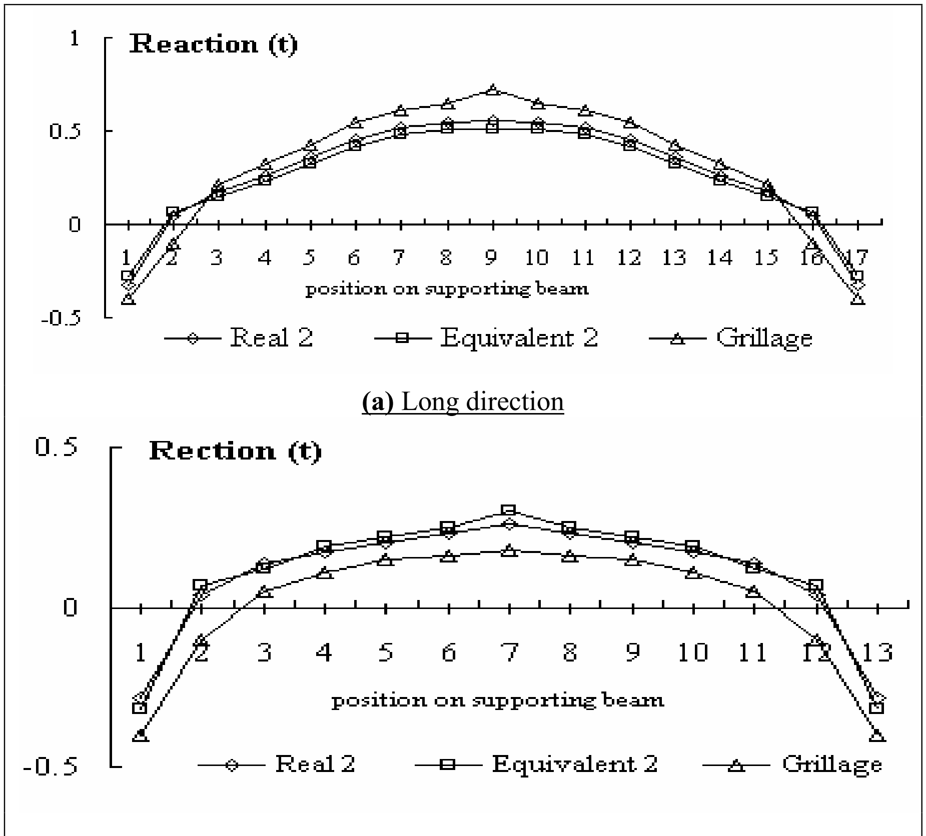
(a) Support transverse to the sheet corrugation



(b) Support parallel to the sheet corrugation

Figure 7: Distribution of reaction forces (*one-way slab*)

Figure (8) shows the distribution of the reaction forces in the Real, Equivalent, and grillage models. Comparison of results proved that the three dimensional finite element real shape model gave the best and the nearest results to those obtained experimentally.



(b) Short direction

Figure 8: Distribution of reaction forces (*waffle slab*)

WAFFLE COMPOSITE SLAB GAINED SUPERIORITY

The most critical mode of failure in one-way composite slab is the slippage between the steel sheet and the concrete. This slippage is expected to be prevented in two ways waffle slabs due to steel sheet ribs configurations; El-Shihy et.al. [8].

One hundred and thirty real models were tested for the sake of comparing the traditional one-way composite slab and waffle composite slab in both construction and composite stages. Each was examined for different slab aspect rations (r) of (1, 1.2, 1.4, 1.6, 1.8 & 2).

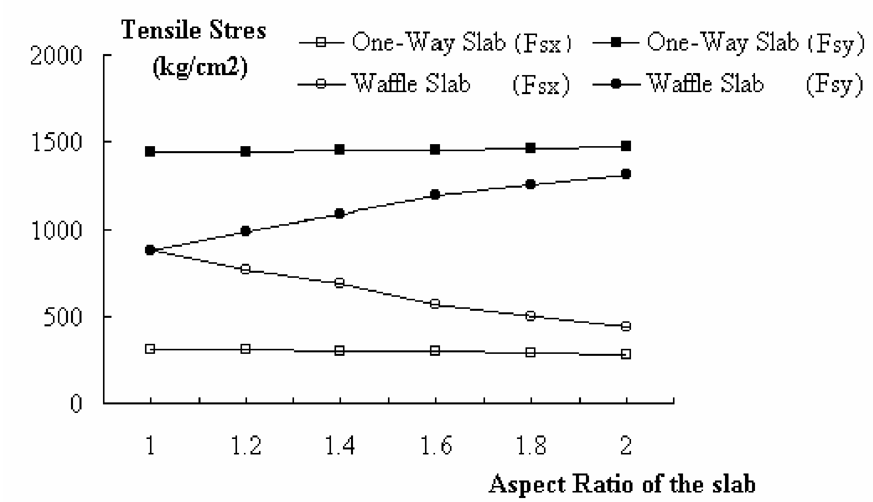
Slabs were examined under an increasing uniformly distributed load until failure. The failure criteria were the maximum concrete compressive stress or the steel sheet yield tensile stress or the allowable slab deflection.

BASIC ASSUMPTIONS SATISFYING THE WAFFLE COMPOSITE SLAB ANALYSIS

1 - Full bond (*interaction*) between steel and concrete.
2 - Linear cracked elastic behavior of concrete.
3 - The effect of supplementary (*secondary*) reinforcements against shrinkage effect and temperature is neglected.

CONSTRUCTION STAGE

Deflection must be controlled in composite slabs construction phase. In one-way slab, loads were transferred mainly in direction of ribs. For example in a one-way composite slab of aspect ratio of 1.4, about 79%; in average; of the total load went through the short direction and the remaining 21% went through the long direction. However, in a waffle composite slab of the same aspect ratio, about 66% of the total load went through the short direction and the remaining 34% went through the long direction. Of course, the better load distribution of the waffle composite slab enhances its structural behaviour; as shown in Figure (9) while in one way composite slab, the stresses are so high in one direction and much lower in the other direction; however in waffle composite slab, the stresses in the two directions were closer to each other.



F_{sx}: Steel sheet tensile stress in long direction.
F_{sy}: Steel sheet tensile stress in short direction.

Figure 9: Comparison of steel tensile stress Level (450 kg/m^2)

COMPOSITE STAGE

Seventy-two waffle and one-way models with different aspect ratios were analysed. All slabs were assumed to be simply supported at four edges. The dead weight of the slabs was taken into account.

Deflection

Small slab aspect ratios gave better behavior of waffle composite slab. Figure (10) declares that for slab aspect ratios of 1.0, 1.2, 1.4, 1.6, 1.8 & 2.0 the maximum deflection of waffle composite slab was lower than that of one-way composite slab by 19%, 18%, 16%, 14%, 9% and 6% respectively. Finally, as the slab aspect ratio increases, the behavior of waffle composite slab becomes closer to that of the one-way slab.

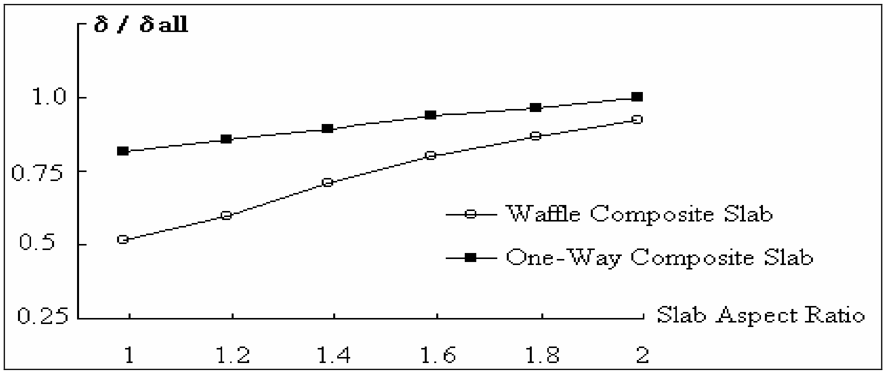
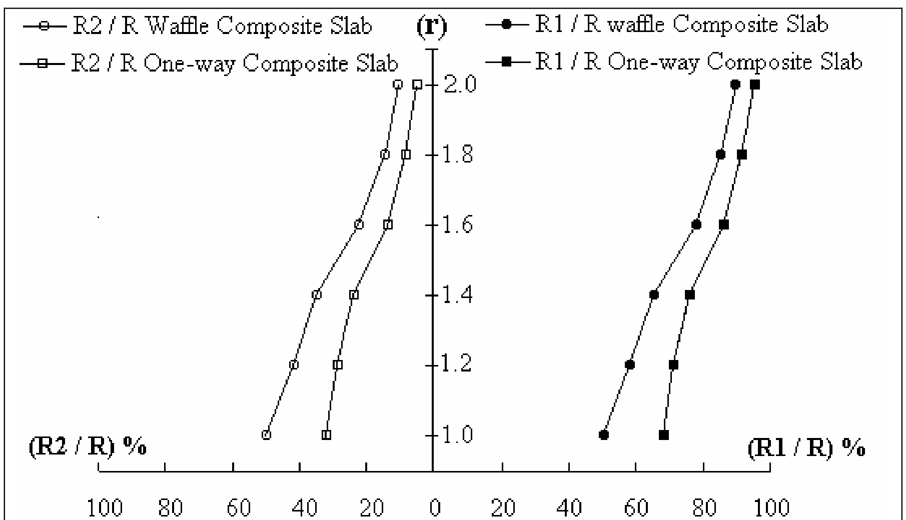


Figure 10: Maximum deflection (450 kg/m^2)

Load Transferred in Each Direction

In general, the load is distributed in a better manner in two-ways slabs than one-way slabs. Figure (11) shows that the load transferred in the short direction in both types of slabs increased as aspect ratio increases. For slab aspect ratios 1.0, 1.2, 1.4, 1.6, 1.8 & 2.0, the waffle slab load transferred through its short direction was reduced by 18%, 13%, 11%, 8.5%, 6.5% and 5% respectively than that recorded for one-way slab. As the slab aspect ratio increases, the behavior of both types of slabs becomes closer.



R_1: Force at support in long direction.
R_2: Force at support in short direction.
R : Sum of **R_1** and **R_2**.

Figure 11: Percentage of load distributed on each side (450 kg/m^2)

Maximum Loading capacity

Figure (12) shows that waffle composite slab could carry higher maximum load more than one-way composite slab by about 12 to 20 % depending on the slab aspect ratio. This relatively higher slab loading capacity leads to reducing the total slab thickness which; of course; means economy.

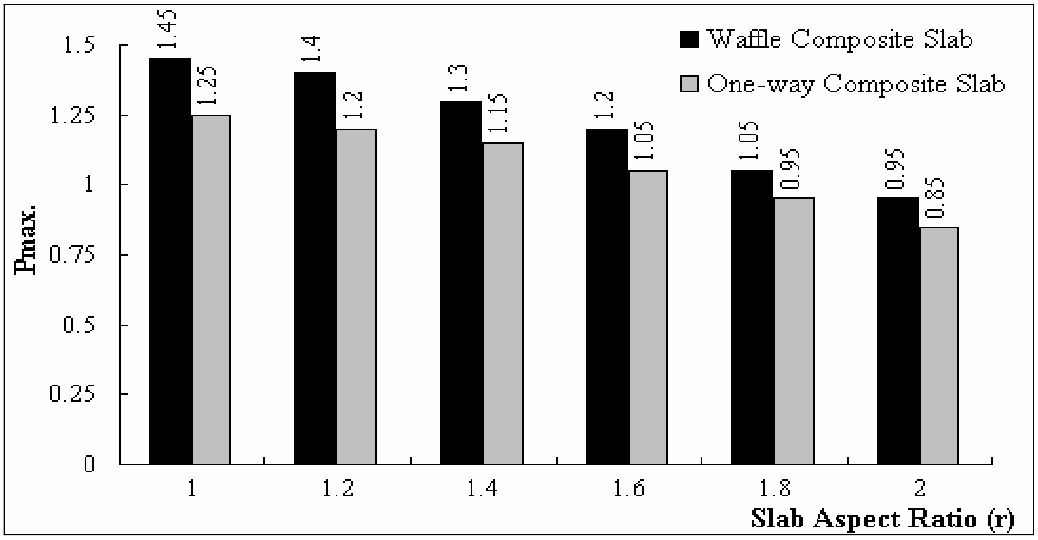
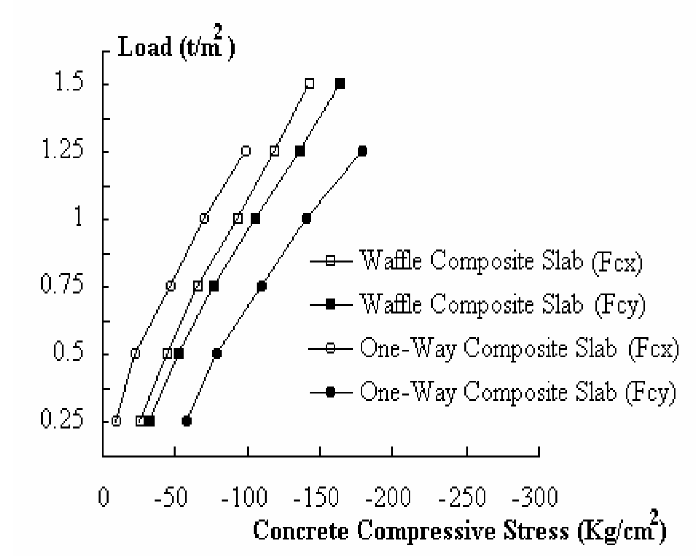


Figure 12: Slab aspect ratio influence on slab loading capacity

Compressive Stress in Concrete

The maximum compressive stresses were recorded and plotted for both waffle and one-way composite slabs due to live load application; as shown in typical Figure 13 for r = 1.2 as an example. It was found that failure happened due to either yielding in steel sheet or excessive slab deflection in both types of slabs. Figure (13) shows that the concrete compressive stress in the short direction of the waffle composite slab was about 19% lower than that of its one-way analogue.

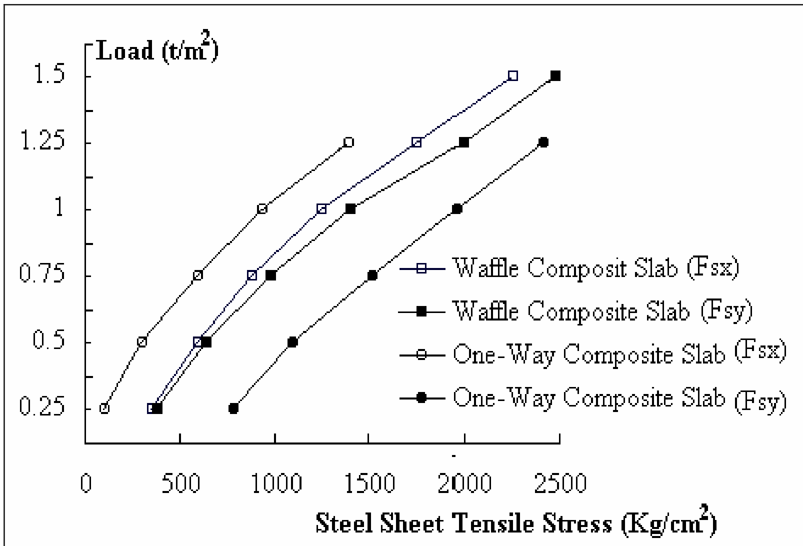


F_{cx} : Concrete stress in long direction.
F_{cy} : Concrete stress in short direction.

Figure 13: Compressive stress in concrete at aspect ratio of 1.2

Tensile Stress in Corrugated Steel Sheet

The tensile steel stresses in of waffle composite slab were found to be lower than the stresses in one-way composite slab, under the same load levels. Figure (14) shows the stresses in steel sheet in waffle slab compared to one-way slab for slab aspect ratio of 1.2 as an example. The tensile stress in the short direction in waffle slab was 17% lower than that of the one-way corrugated one.



F_{sx}: Steel sheet tensile stress in long direction.
F_{sy}: Steel sheet tensile stress in short direction.

Figure 14: Tensile stress on corrugated steel sheet in waffle and one-way composite slabs

Effect of Generating and Increasing the Number of Ribs in the Long Direction

Five three-dimensional finite element real shape slab models of dimensions equal to (3.66 × 4.88 m) were used to study the effect of variation of composite slab behavior due to changing it gradually from one-way to waffle composite slab. Table (2) shows the percentage of load transferred in each slab direction due to this variation.

Table 2: Effect of decreasing number of ribs in the long direction [at load (P) ≈ 25% of $P_{max.}$]

Model	Load transferred [%]		Number of ribs in the long direction
	Short direction	Long direction	
Slab 2a	71.9	28.1	0.0 (one-way slab)
Slab 2b	68.3	31.7	4
Slab 2c	66.9	33.1	8
Slab 2d	63.5	36.5	16
Slab 2e	62.6	37.4	24 (two-way slab)

PARAMETRIC STUDY

Testing program characteristics

One hundred waffle composite slabs were tested in order to investigate the effect of some significant parameters on their behavior. These factors were slab aspect ratio, slab boundary conditions, steel sheet profiles, varying the steel sheet corrugation cells aspect ratio, and increasing the steel sheet depth with a constant total depth of the slab. The previously mentioned three-dimensional finite element real shape model was considered. The dimensions of the slabs varied from (7.08 × 7.08 *m*) to (7.08 × 3.48 *m*). A typical considered corrugated steel sheet deck section; known as CF 46; PMF [9]; was used. Except in the comparison between the different steel sheet shapes, a trapezoidal steel sheet section called PEVA 45; PMF [9]; and a re-entrant steel sheet section were used. The details of the three different steel sheet shapes used in the study are described in Table (3) and Figure (15).

Table 3: Corrugated steel-deck sections properties

Steel-Deck Section	Thickness (mm)		Weight (kN/m^2)	Moment of Inertia (cm^4/m)	Net Section Area (cm^2/m)
	Nominal	Design			
CF 46 *	1.2	1.16	0.112	53.0	14.59
PEVA45 *	0.94	0.9	0.102	51.5	13.23
Re-entrant Profile **	0.9	0.86	0.127	67.0	16.55

* **Ref. [9] .**
** **Ref. [10] .**

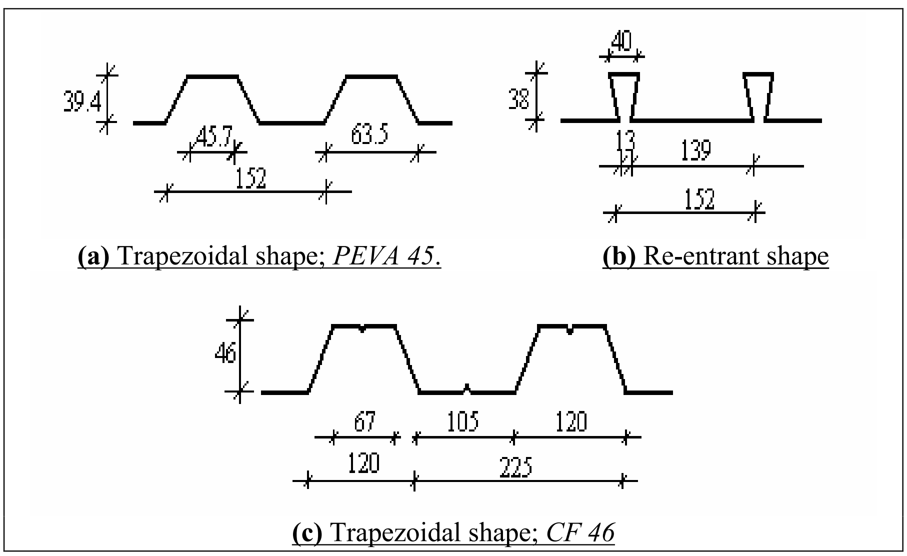


Figure 15: Cross section details of steel-deck (sheet) profiles [All dimensions in (mms)]

The overall slab thickness was 180 mm in all models according to the ECCS [7] for one-way composite slab. The own weight of the tested slabs was taken into account. The live load was increased gradually till one of the failure criteria limits is reached.

ANALYSIS AND DISCUSSION

Slab aspect ratio

Thirty slab models were analyzed to declare the effect of slab rectangularity. The same corrugation dimensions were typical in both slab directions (corrugation cells aspect ratio equal to 1.0). The maximum loads of resistance; ($P_{max.}$); and failure modes of suggested models are summarized in Table (4).

Table 4: Maximum loads of resistance and failure modes of slabs with variable aspect ratios

Slabs	Aspect Ratio (r)	Ly / Lx		P_{max} (t/m^2)	Mode of failure
		Lx (m)	Ly (m)		
A1 - A5	1.0	7.08	7.08	1.0	Deflection (Serviceability)
A6 - A10	1.2	7.08	5.73	1.2	Deflection (Serviceability)
A11 - A15	1.4	7.08	5.06	1.35	Yielding in Steel Sheet
A16 - A20	1.6	7.08	4.38	1.45	Yielding in Steel Sheet
A21- A25	1.8	7.08	3.93	1.5	Yielding in Steel Sheet
A26 - A30	2.0	7.08	3.48	1.54	Yielding in Steel Sheet

- All slabs are simply supported at four edges.
- CF 46 steel sheet [9].

It was recorded that slab deflection decreased as slab aspect ratio increased while the percentage of load transferred in the long direction decreased, and the corresponding load value transferred in the short direction increased; Figure (16).

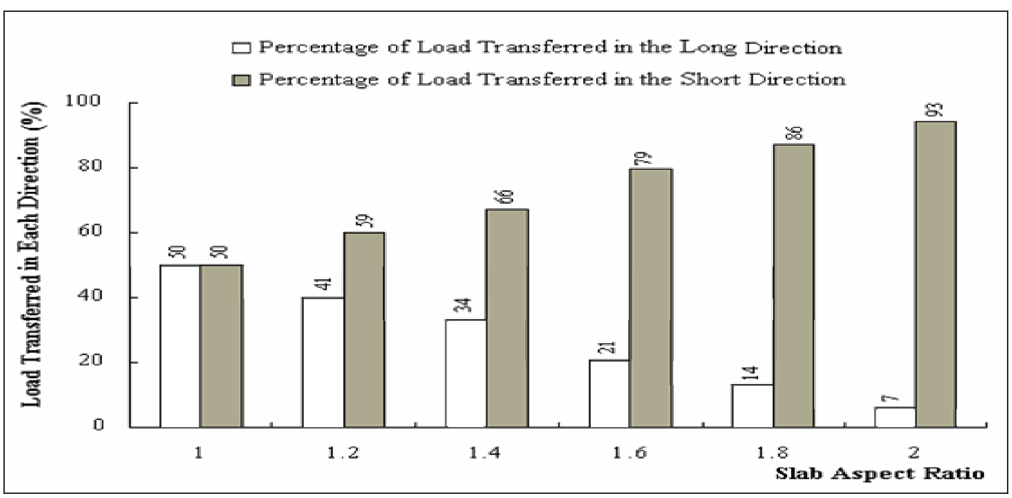


Figure 16: Effect of slab aspect ratio on percentage of load transferred in each direction

Slab Boundary Conditions

Slab boundary conditions was found to be a very important factor, the fixed edges are more recommended as the loads gets higher. The effect of slab boundary conditions on the results is shown in Figure (17).

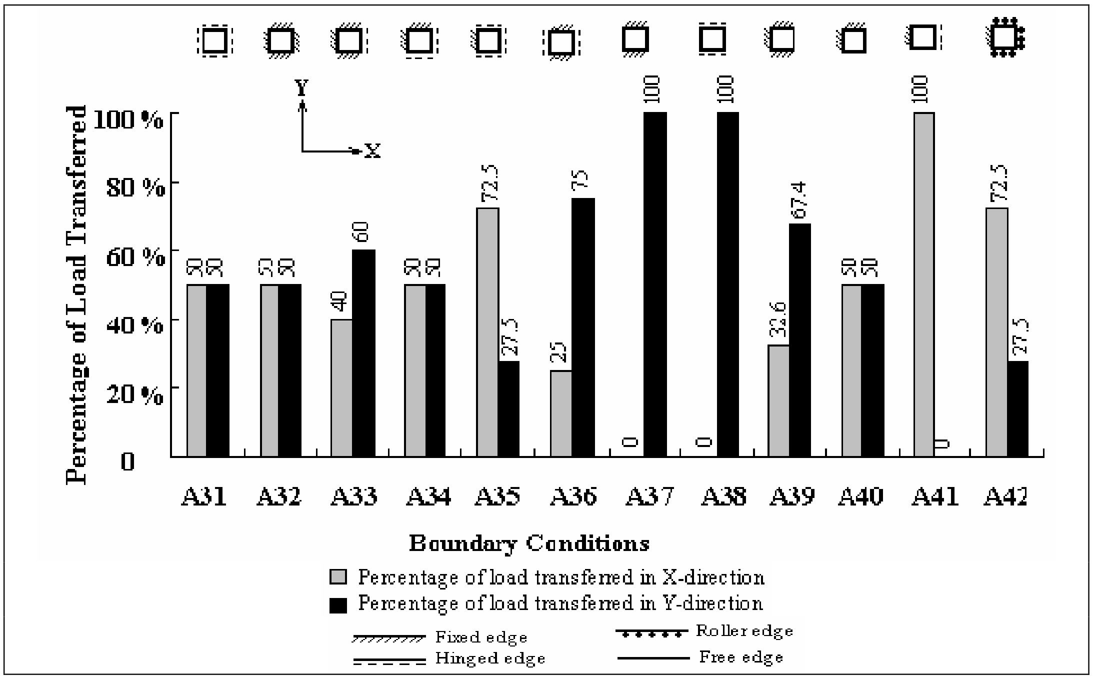


Figure 17: Percentage of load transferred in each direction

Steel-deck (sheet) profile

A comparison was held between a waffle trapezoidal and a re-entrant steel sheet shape with almost the same corrugation cycle dimensions; Figures (1 and18).

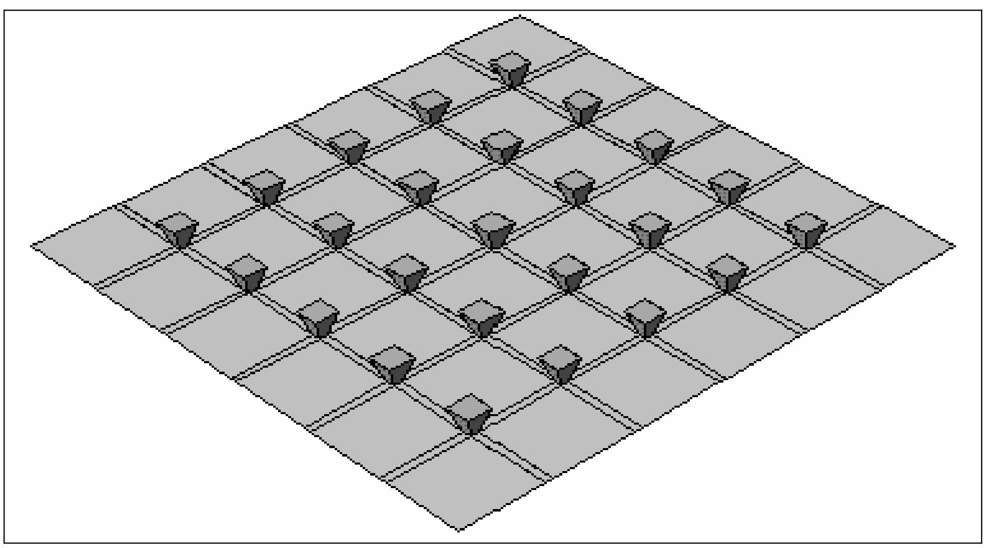


Figure 18: Suggested shape for re-entrant waffle steel sheet

Almost the same deflection, stresses and the percentage of load transferred in each direction were recorded in the two types.

Steel sheet corrugation cell aspect ratio

The dimensions of the traditional steel sheet cycles of the one-way composite slab were used in the two directions of the tested slabs; Figure (19). The cells were kept constant in one direction, and varied in the other. Eighteen models divided into two groups were tested. *The first group* had square slabs (7.0 × 7.0 m), where the corrugation cells were oriented parallel to **Y**-direction. *The second group* had rectangular slabs of aspect ratio r =1.4, (7.08×5.055 m).

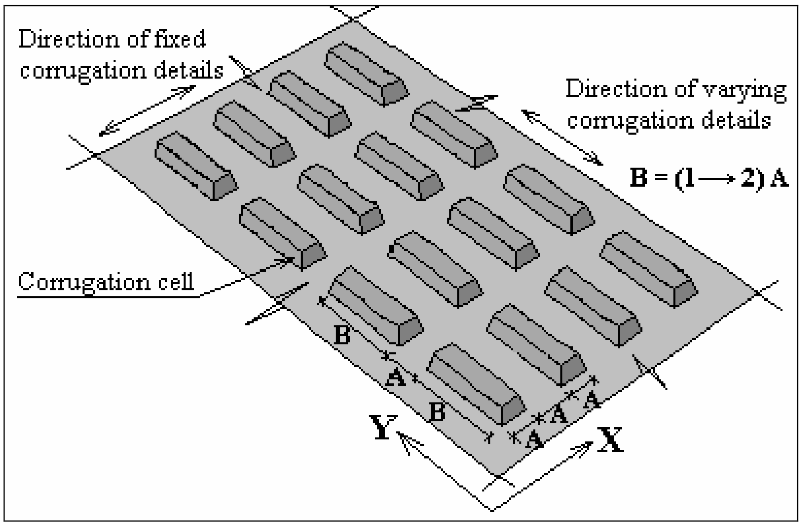


Figure 19: Steel sheet configurations

The rectangular slab had two cases. *Case (A)* where the cell long direction was parallel to slab long direction and *Case (B)* where the long direction of the cell was perpendicular to the slab long direction; as shown in Figures (20-a and 20-b) respectively .

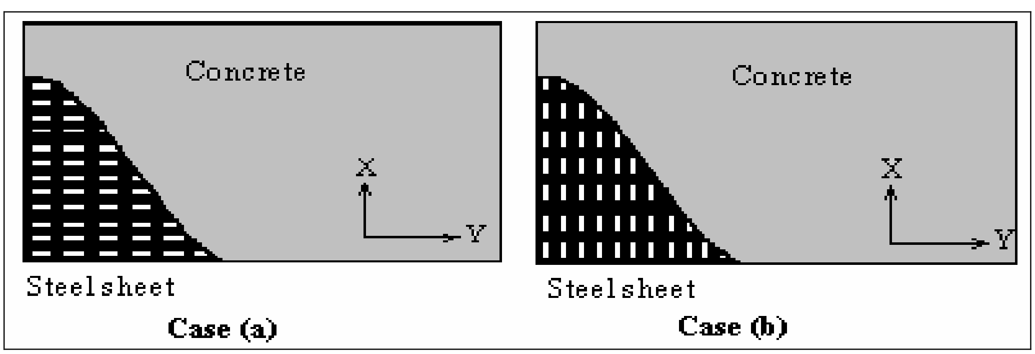


Figure 20: Orientation of the corrugation cells with respect to composite slab layout

The increase of the corrugation cell aspect ratio decreased the percentage of load transferred in the long direction in both square and rectangular slab of (Case B), while it was increased in rectangular slabs of (Case A) as shown in Figure (21).

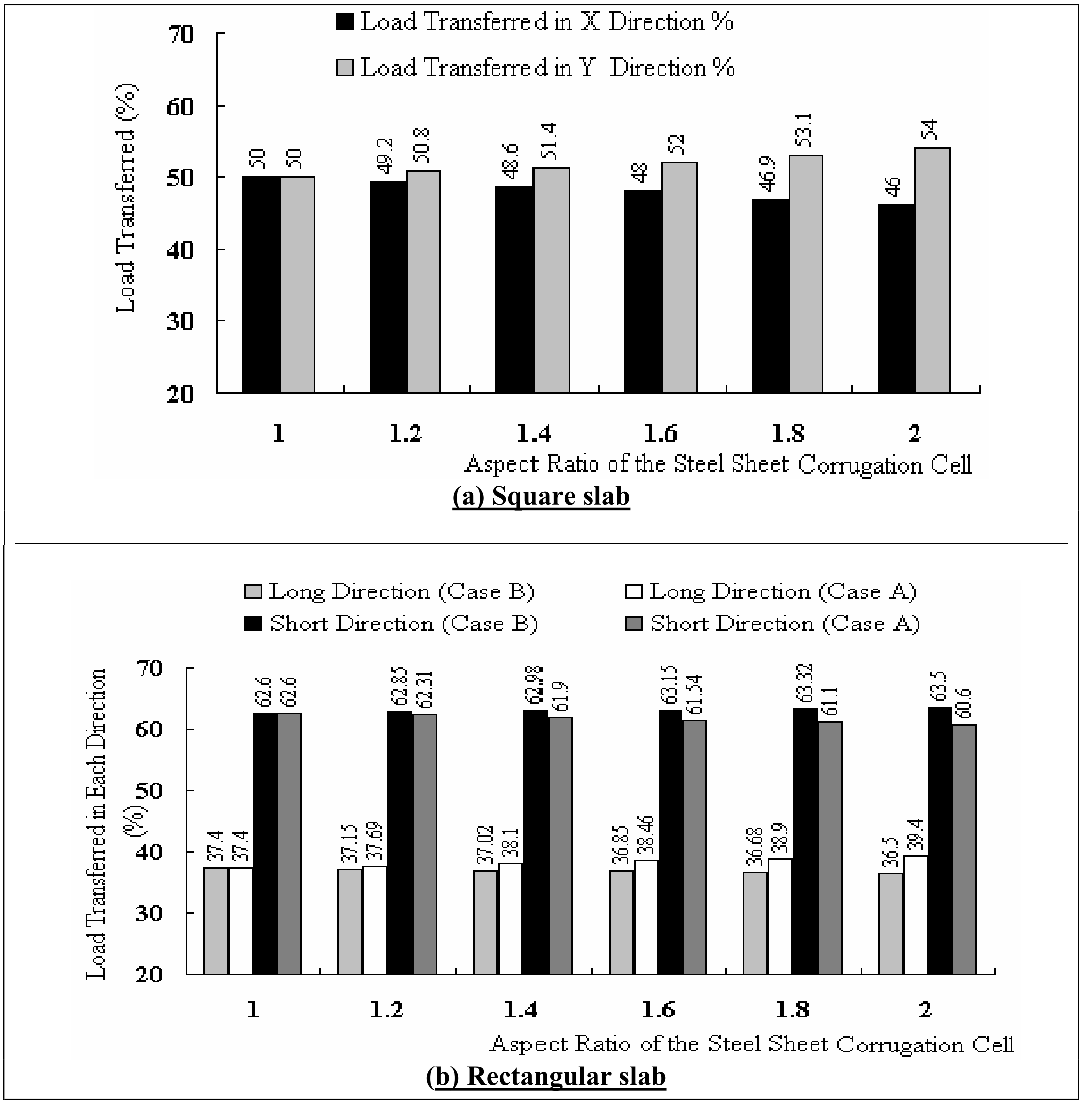


Figure 21: Load transferred in each direction

Deflections increased in both square and rectangular slabs of (Case A) and decreased in slabs of (Case B). Both steel and concrete stresses decreased in the long direction in square and (Case B) slabs, and increased in the long direction in (Case A) slabs with the increase of the steel sheet corrugation cell aspect ratio.

CONCLUSIONS

- The 3-D finite element real shape model was found to be the best modeling technique to represent both waffle and one-way composite slabs.

- In construction stage, waffle composite slab proved its superiority on its one-way analogue by reducing steel sheet stress and the percentage of load transferred in the short direction.
- In composite stage waffle composite slab sustained loads higher than its one-way analogue, and permitted lower deflection value. Steel and concrete stresses in *waffle* composite slab were lower and better load distribution along the two orthogonal directions was gained. In addition, the way by which waffle steel sheet is formed, prevents the slippage between the sheet and the concrete. In architectural point of view, the good appearance of the waffle shape saves the cost of constructing artificial ceiling.
- Increasing slab aspect ratio decreased slab deflection and increased steel sheet and concrete stresses in the short direction. Symmetric-fixed boundaries lead to the best behavior of waffle composite slab. The re-entrant waffle corrugated sheet permitted lower deflection, higher steel sheet and concrete stresses than the trapezoidal shape, and it allowed the same percentage of load distribution in the two directions. Square corrugation cell of steel sheet was found the best in both square and rectangular slab. A better behavior of waffle composite slab was obtained when the steel sheet depth was equal to one third of the total slab depth.
- In general, the behavior of waffle composite slabs is superior and it is strongly recommended to manufacture new steel sheet configurations to allow using this new type of composite slabs [11].

REFERENCES

[1] Porter, M. L. and Ekberg, C. E. Jr., “Behavior of Steel- Deck-Reinforced Slabs”, *ASCE, Journal of the Structural Division,* Vol. 103, No. ST3, PP. 663-677, 1977.

[2] Porter, M. L. “Analysis of Two-Way Acting Composite” *ASCE, Journal of Structural Engineering*, Vol. 111, No. 1, pp. 1-18, 1985

[3] An, L. “Load Bearing Capacity and Behavior of Composite Slabs with Profiled Steel Sheet”, Ph.D. Thesis Presented to Chalmers University of Technology, Goteborg, SWEDEN, 1993.

[4] Khalaf, M. , El-Shihy, A. , Abdel-Salam, S. and El-Hoseiny, O “New Modeling of Composite Floors with Profiled Steel Sheet”, *Engineering Research Journal*, Faculty of Engineering Technology, Helwan University, Mataria, Cairo, EGYPT, Vol. 3, pp. 251-271, 1995.

[5] “SAP2000”; A Structural Analysis Program; University of California, Berkeley, CA, U.S.A., Revised 1997.

[6] Klaiber, F. W. and Porter, M. L., “Uniform Loading for Steel–Deck Reinforced Slabs”, *ASCE, Journal of the Structural Division*, Vol. 107, No. ST11, PP. 2097 – 2110, 1981.

[7] “European Recommendations for Steel Construction*: The Design of Composite Floors with Profiled Steel Sheet* ", 1975, Publication No. 14, Committee No. 11.

[8] El-Shihy, A.M. , Shehab, H. K. , Khalaf, M.& Mustafa, S. A. “Analysis of Waffle Composite slabs” 2nd International Structural Engineering and Construction Conference (ISEC-02), Sep. 23-26, 2003 , Rome, ITALY.

[9] Precision Metal Forming Limited; PMF; “Profiles for Concrete for Fast; Long Span Flooring and Roofing”, Swindon Road, Cheltenham, Glaucestershire GL51 9LS, ENGLAND.

[10] Engineers in Reinforced Concrete , “Quick Span Construction Limited”, 2Market Close , Poole , Dorset BH15 1NQ, ENGLAND, 1982..

[11] Mustafa, S. A. “Waffle Composite Slabs”, M. Sc. Thesis Presented to Structural Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, El-Sharkia Governorate, EGYPT, 2002.