Finite Element Modeling and Analysis of Sandwich Dry Floor Slab

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***Abstract*— Behaviour of composite dry floor slab system constructed using profiled steel decking and plywood panels is studied by conducting linear and non-linear finite element analysis. The parameters considered are steel sheeting and plywood thickness, profile shape of the deck, and single (top) and double skin (top and bottom) plywood panels. The main focus of the study is on the determination of slab strength under bending and load distribution behaviour in two-way action. A bending test of single skin specimen was conducted to obtain load-deflection behaviour for verification of the finite element model. The results of the analysis indicate that the steel sheeting thickness is the main parameter that governs the slab load bearing capacity while plywood thickness minimally affects the slab strength. Slab with double skin plywood can take the load three times larger than that with single skin plywood. Slab made with trapezoidal shape steel deck has a better load distribution in the transverse direction (two-way system) compared to those made with rectangular and dove tail shape deck. The information obtained from this study can be used as a guide for application of composite dry floor slab system.**

***Index Term*-- Dry floor slab, profiled steel deck, composite slab**

I. INTRODUCTION

Floor slab in permanent building mostly constructed using either reinforced concrete or composite steel-concrete system. Construction of these types of slab system, which is normally involving concrete poured on site, is time consuming. Besides, the system is labour intensive, expensive, heavy, and are not suitable for use to construct temporary structures such as disaster relieve centre, temporary workers' hostel, temporary storage platform, etc. A more suitable slab system for these types of structure is using lightweight, dry construction materials where concrete is not used. Cold- Formed steel decking sandwiched with plywood panels is one of the options that is feasible for construction of the temporary structure. Its advantages are fast construction, no wait for curing, lightweight, easy handling and does not require skill labour. Furthermore, the reduction of the slab weight due to its lightweight material can reduce the foundation size considerably.

The composite action of the dry slab is achieved by connecting the profile steel sheeting and dry board using mechanical screws as shown in Figure 1. The system has no concrete component, hence is known as dry slab system. This system was first introduced by Wright et al. [1] which was intended for use as flooring unit in domestic applications and as an alternative to the traditional timber joist floor system. According to Gandomkar et al. the screw spacing (S) would give major effect on the stiffness and natural frequencies of the system, where panels with closer screw spacing is stiffer than panels with larger screw spacing [2]. In addition, the peak acceleration of the system is also reduced by increasing the thickness of steel deck and dry board, and decreasing screw spacing [3]. Mangesha [4] stated that the use of profiled steel sheeting and dry board panel filled with polystyrene can improve the performance of the system compared with the panels without infill materials. However, Akhand as reported by Surat et al. [5] had studied the behaviour of the continuous floor system in non- linear and ultimate range.

The rational design of the dry floor system requires the knowledge of the behaviour of the structure in its ultimate load range. The ultimate behaviour of this structural system essentially involves a complex interaction between materials and geometric nonlinearities in the inelastic range. Moreover, the structural behaviour and strength of the system were greatly influenced by the properties of the basic components forming the system, e.g., the steel sheeting, dry board, and the degree of interaction between them [6,7].

The structural response of a composite dry floor slab is predominantly nonlinear. A realistic structural analysis to predict the ultimate load capacity and load-deflection behaviour should cater the nonlinearities of the component materials. In this study, finite element analysis of dry floor slab system made with profiled steel decking sandwiched with plywood panels on top and bottom face of the deck is conducted. The nonlinear material behaviour of the steel deck and plywood were considered. The objectives of the study are to investigate the ultimate load capacity, stiffness and load distribution behaviour in one and two-way support. Plywood and steel sheeting thickness, single and double skin plywood panel, and steel profile shape are the variables considered in the analysis.

II. BENDING TEST

Flexural tests on a dry floor specimen using plywood and cold formed steel deck were carried out in the laboratory. The load-displacement results from the test were used to validate the preliminary finite element model. This test specimen utilised Steelon Deck Plate (SDP) profiled steel deck as shown in Figure 2. The steel sheeting thickness is 0.8 mm. Eighteen mm thick plywood was attached to the top side of steel deck using a self-drilling screw of 3 mm and 38 mm in diameter and length respectively. The screws were arranged to have a spacing of 50 mm. The support to the line load is 600 mm long and the total span is 2400 mm long. The test arrangement and specimen length is shown in Figure 3. The test was conducted using Magnus frame, where the load is applied through hydraulic jack. The load is measured using load cell,

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and the displacements were recorded using linear vertical differential transducer (LVDT). The loading was gradually increased by one (1) kN until the model failed which was indicated by an abrupt reduction of load and large increment of vertical displacement.

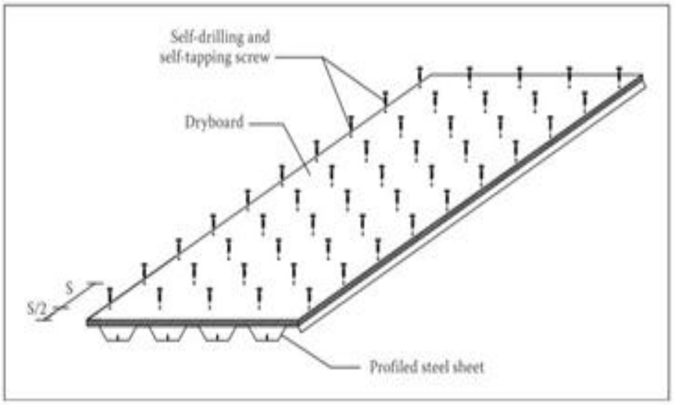


Fig. 1. The component dry floor system

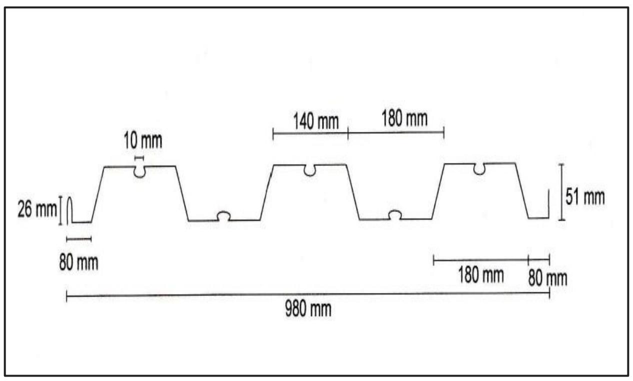


Fig. 2. SDP steel deck profile

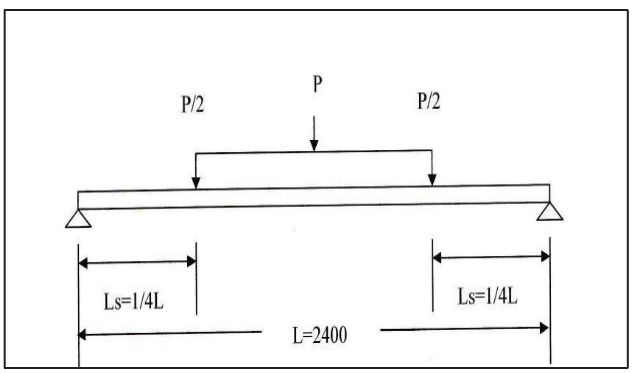


Fig. 3. Load arrangement for the flexural test. P/2 is line loads along the slab width

TABLE I
MATERIAL PROPERTIES OF STEEL DECK

Steel properties	Deck top flange and web	Deck bottom flange
Elastic modulus (N/mm^2)	150E3	203.4E3
Poison's Ratio	0.3	0.3
Yield Strength (MPa)	250	320

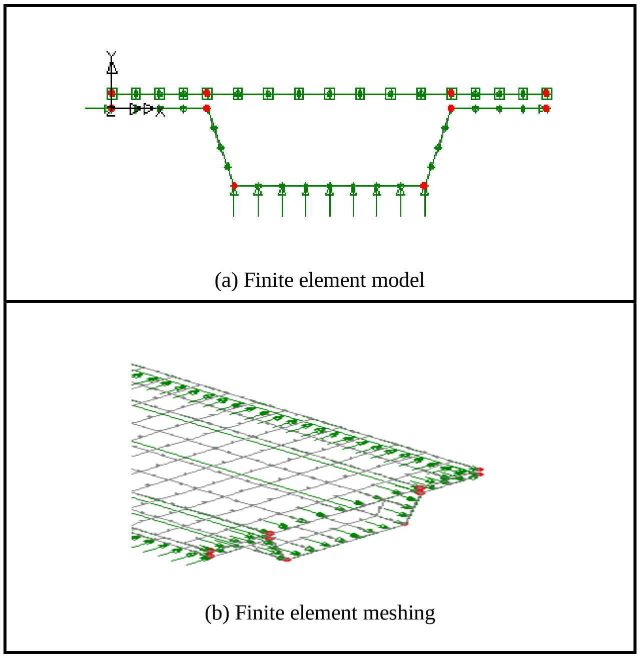
III. FINITE ELEMENT MODEL

A. *Preliminary Model*

A preliminary finite element models similar to the test specimen was developed and analysed using LUSAS Version 13.6 [8]. The purpose of the preliminary model was to determine suitable modelling attributes, such as element type, material properties, interface connection and boundary condition. Due to symmetric loading and geometry, only one-rib width of the steel deck (320 mm) and one-half of the span length (1200 mm) was considered in the preliminary development of the FE model. The load-deflection curves from the analysis results of the preliminary model were compared against the test results. When the load-deflection curves matched each other in terms of deflection and maximum load, the model attributes were then used in the subsequent modelling for parametric study.

B. *Structural Model*

Both steel deck and plywood were represented by thin shell (QSL8) element. The surface representing plywood panel was separated from the top flange of the steel deck at 10 mm gap but tied to each other completely using tied mesh. As such, the plywood and the steel deck were assumed to be in full interaction where no sliding and no separation occurred. Vertical restraint was provided at the end of deck bottom flange, while horizontal restraint in the transverse direction was provided along the length at both edges of steel deck and plywood meshes. Horizontal support in the longitudinal direction was applied at the mid-span end (Figure 4).



(a) Finite element model

(b) Finite element meshing

Fig. 4. Finite element model and meshing

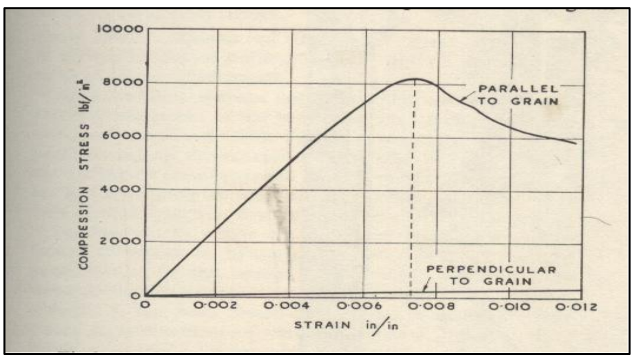


Fig. 5. Graph of Stress–Strain of Plywood (Curry and Hearmon) [9]

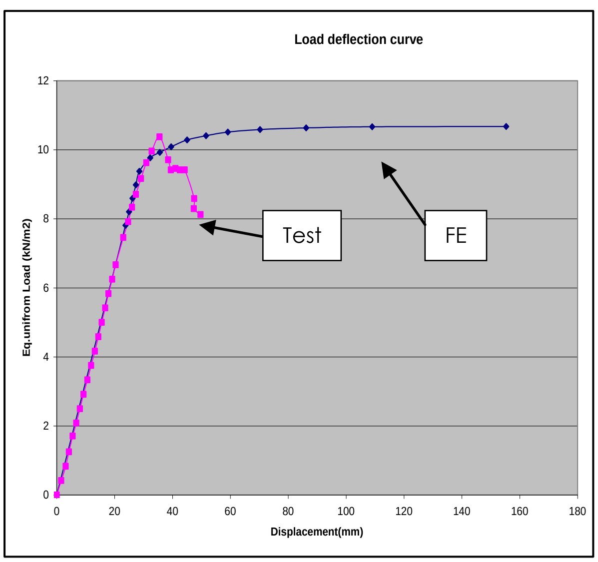


Fig. 6. Load-deflection graphs for preliminary model

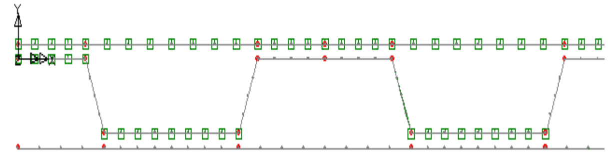


Fig. 7. Model for Double Skin Plywood

TABLE II
PLASTIC STRESS-STRAIN CURVES OF PLYWOOD

Stress(N/mm2)	Plastic Strain (mm)
34.5	0
38.0	0.0004
41.0	0.0008
45.0	0.0012
48.0	0.0018
52.0	0.0022
55.0	0.0028
55.9	0.0033
55.2	0.0044
51.7	0.0052

C. Material Properties

Steel deck material was assumed as isotropic elastic-perfectly plastic behaviour similar in both tension and compression. The initial trial values were based on the manufacturer’s catalogue and then the values were adjusted in several trials until the load-deflection curves of the analysis matched the curve from the test. Lesser yield strength values were assigned to the top flange and web to account for the reduced strength of steel due to ineffective length for thin plate under compression, possible local buckling in the top flange and top part of the web, and also weakening in the steel strength due to embossment in the web. The final material properties of steel as given in Table 1 were then used in the analysis to study the response of the slab system under various parameters.

For the plywood material properties, the non-linear portion of stress-strain curve were based on the graph of stress-strain as proposed by Curry and Hearmon as shown in Figure 5 [9]. The stress-strain curves of parallel to grain was used in the model. Young's Modulus value of 8.1643 N/mm^2 and Poisson's ratio 0.2 were assigned while the non-linear portion of stress-strain values are shown in Table 2. The non-linear analysis was carried out to study the effect of steel sheeting thickness, plywood thickness, and double and single skin plywood panels. Only material non-linearity was considered.

In the study of load distribution behaviour in two-way slab made with the different geometry of deck profiles, a linear elastic analysis was carried out on the 1920 mm wide x 2400 mm long model. The corrugation of the deck is along the longer span. The slab was supported in a vertical direction along all sides. A total of 1000 N load was applied uniformly on the plywood surface. Total reaction force at longitudinal and transverse edges was determined and the amount was compared with the total applied load.

IV. Result of Preliminary Model

The preliminary finite element analysis result was verified by comparing the load-deflection graphs with that of test results as shown in Figure 6. Uniformly distributed load, w is represented in the graph so that a sensible comparison between models can be made. It was obtained by equating the maximum moment from the test;

$$M_{max} = \frac{P}{2} L_S$$

with the maximum moment for beam under uniform loading ;

$$M_{max} = \frac{wL^2}{8}$$

It should be noted that there is no declining portion of finite element graph because the steel material was assumed as perfectly plastic and no buckling of a plate was modelled. In the test, the slab failed by yielding of plywood and local crippling of the top flange of steel deck under the line load after the ultimate load was reached. As such, the load-deflection graph from the test shows a remarkable decrement of load after reaching peak value.

A. *Parametric study*

Once the preliminary model was verified, the finite element model was expanded to the double plywood skin model (Figure 7) to study the effect of parameters, namely double skin plywood panel, two-way load distribution, deck profile geometry, thickness of plywood, and thickness of steel sheeting. The list of plywood and steel sheeting thickness is given in Table 3. The load-deflection behaviour was extracted from the analysis data and the maximum loads were compared between results of similar parameters.

Three type of corrugations of steel deck as shown in Figure 8 were considered in the linear analysis to study the two-way load distribution behaviour.

B. *Analysis Results*

The load-deflection graphs for models with different steel thickness using 18 mm plywood panel is shown Figure 9 while the load-deflection graphs for models with different plywood thickness using 0.8 mm steel sheeting thickness is shown in Figure 10. Maximum loads obtained from these graphs and single plywood skin models are listed in Table 4. The uniform loads represented here are for one-rib deck corrugation where the width is 320 mm.

TABLE III
LIST MODELS WITH STEEL SHEETING AND PLYWOOD THICKNESS

Model ID	Steel Thickness (mm)	Plywood Thickness (mm)	Loading Types (N/mm^2)
08S18P	0.8	18.0	Floor load
10S18P	1.0	18.0	Floor load
12S18P	1.2	18.0	Floor load
15S18P	1.5	18.0	Floor load
18S18P	1.8	18.0	Floor load
08S9252P	0.8	9.3	Floor load
08S127P	0.8	12.7	Floor load
08S923P	0.8	23.0	Floor load
08S925P	0.8	25.0	Floor load

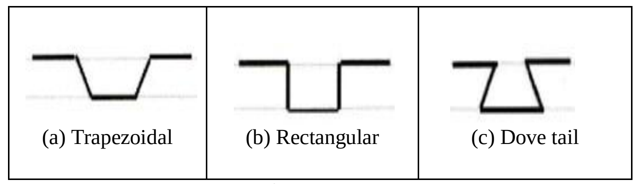


Fig. 8. Type of Corrugations Steel Deck

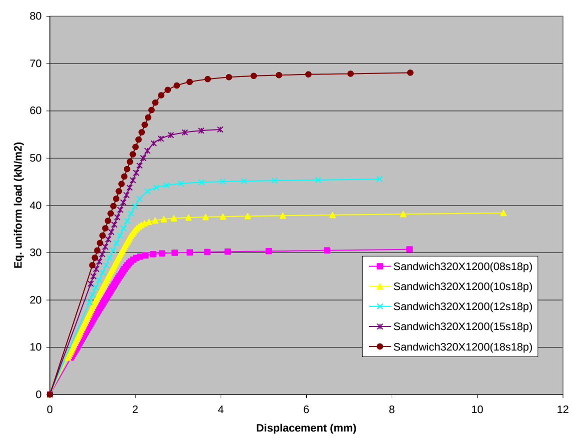


Fig. 9. Load-deflection graphs for double skin models with different steel thickness

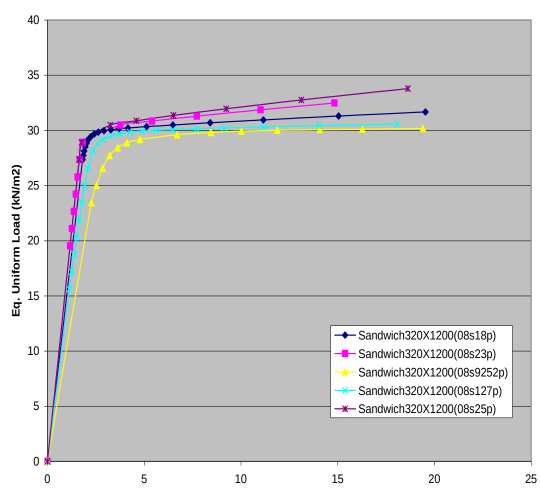


Fig. 10. Load-deflection graphs for double skin models with different plywood thickness

TABLE IV
MAXIMUM LOADS FOR DOUBLE AND SINGLE PLYWOOD SKIN MODELS

Model ID	Steel Thickness (mm)	Plywood Thickness (mm)	Maximum Load (kN/m^2) Double skin slab	Maximum Load (kN/m^2) Single skin slab	Double/ Single skin
08S18P	0.8	18.0	30	10	3
10S18P	1.0	18.0	36.5	12.1	3
12S18P	1.2	18.0	43.8	14.4	3
15S18P	1.5	18.0	54	17.7	3
18S18P	1.8	18.0	65	21.0	3
08S9252P	0.8	9.3	29	9.4	3
08S127P	0.8	12.7	29.7	9.5	3
08S23P	0.8	23.0	30.5	10.1	3
08S25P	0.8	25.0	30.5	10.3	3

The results show that the thickness of steel deck sheeting is the most important parameter that affect the load capacity of the slab system. The increment of the sheeting thickness from 0.8 mm to 1.8 mm resulted in the increment of load carrying capacity by 116% for double skin slab and 110% for single skin slab. The load capacity increases linearly with the steel sheeting thickness for both slabs (Figure 11) with the double skin slab increases faster than the single skin slab. On the other hand, the effect of plywood thickness on the slab capacity is minimal (Figure 12).

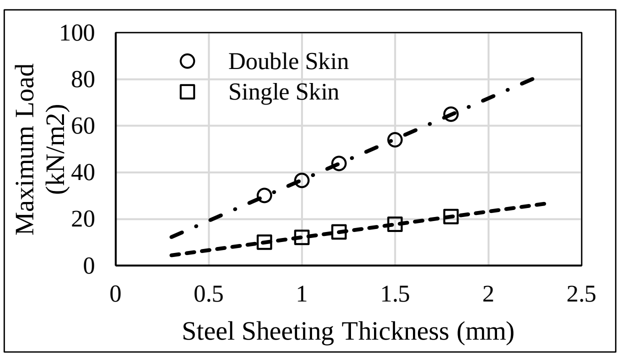


Fig. 11. Maximum load versus steel sheeting thickness

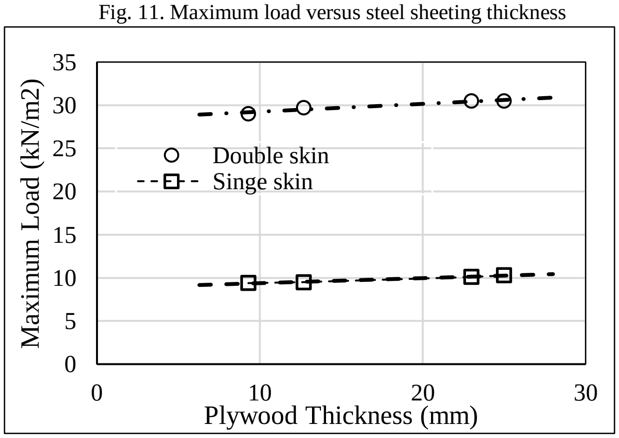


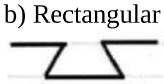
Fig. 12. Maximum load versus plywood thickness

The increment of plywood thickness from 9.3 mm to 25 mm resulted in a slight change of load carrying capacity; that is by 5.2% and 9.6% for double and single skin respectively. The load carrying capacity of double skin system is three times larger than the single skin system and the increment is consistent for all models (Table 4).

In the analysis to determine the load distribution behaviour of the dry slab made with different steel deck profiles, double skin system was used. The total reaction forces at each side along longitudinal and transverse direction was recorded. The percentage of load transfer to each side of the slabs are shown in Table 5. As expected, the largest portion of the load is distributed along the longitudinal length. This is in confirmation with the stiffness of the deck that is obviously greater in the longitudinal direction due to deck corrugation orientated in the longitudinal length.

The load distribution in the transverse direction is larger for a slab with trapezoidal deck, which is 16% versus 6% for slabs that use rectangular and dove tail profile. Clearly, it is important to consider the orientation of the corrugation in the design of beams supporting this type of slabs.

TABLE V
PERCENTAGE OF THE TOTAL LOAD MEASURED AS THE SUPPORT REACTION FORCE THE EDGES OF THE SLAB

Steel Profile	% of Load Short Span Edge (Lx)	Distribution Long Span Edge (Ly)
 a) Trapezoidal	16	84
 b) Rectangular	6	94
 c) Dove tail	6	94

Note: Short Span edge is the edge parallel to the longitudinal length. The deck corrugation is in the longitudinal length direction.

V. SUMMARY AND CONCLUSION

Load bearing capacity and two-way load distribution behaviour of composite dry slab system were studied. A bending test and linear and non-linear finite element analysis were carried out. Bending test data was used to verify the finite element model. The non-linear finite element analysis was conducted to determine the effect of various parameters. From this study, it can be concluded that:

(a) The load carrying capacity of double skin dry floor slab is three times higher than the single skin slab. It is significant to use double skin (sandwich) dry floor slab for construction using this type of slab system.

(b) The thickness of steel sheeting is the most important factor to be considered in the construction of composite dry floor slab system.

(c) The thickness of plywood does not provide a significant effect on the load bearing capacity of composite dry floor slab system.

(d) Deck profile with trapezoidal shape can distribute more loads to the transverse in the case where the slab is supported at all sides.

ACKNOWLEDGEMENT

This research was financially sponsored by the Fundamental Research Grant Scheme, Public Works Department (JKR), Universiti Teknologi Malaysia, Ministry of Science, Technology and Innovation and Universiti Teknologi Mara.

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