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VERIFICATION FOR MODELING OF ULTIMATE LOAD FOR LIGHTWEIGHT PALM OIL CLINKER REINFORCED CONCRETE BEAMS WITH WEB OPENINGS USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

This paper suggests verification for modeling of ultimate load of lightweight Palm Oil Clinker (POC) reinforced concrete (RC) beams with web openings using the Response Surface Methodology (RSM). The proposed model is developed to predict and verify the ultimate load for a comparison with the experimental measurements and optimizes load capacity and design accordingly. The ultimate load has been investigated against three parameters, namely depth of beams, location of openings and length of openings. The results of this work show that the technologically advanced model has good adaptability and high accuracy.

Keywords: palm oil clinker; beams with web openings; response surface methodology

1. INTRODUCTION

Structural members are frequently confronted with the problem of having to provide openings as passage for utility ducts and pipes to accommodate essential services such as plumbing, heating, air conditioning, and telephone and electricity cables. Obviously if openings through beams or girders can be made for ducts or pipes without sacrificing structural integrity, the dead space in false ceilings can then be eliminated and substantial construction cost savings can be realized. This is particularly important in multi-storey buildings where the use of openings in the beams can reduces the total height of building, leading in turn to a multiplicity of savings. A lot of researches for reinforced concrete (RC) beam with openings using Normal Weight Concrete (NWC). Recently, the construction materials technologies and building practice have evolved. Construction industry is the biggest energy consuming sector. With increasing urbanization, natural resources are being utilized in the construction. Environmental conscious buildings design has become important. The green building concept is the construction of energy efficient buildings which result in reduced air and water pollution, less water consumption, limited waste generation and increased user productivity. The awareness of green building has begun and with building industry poised for a major growth, green building industry would be a mantra of the building industry in future. Going green is a sustainable building technology for the environmentally harmonious cities. Malaysia, being the world leading producer of palm oil, generates an enormous amount of waste in the form of oil palm shell in the production process (D.C.L. Teo, et al., 2007; Mannan, M.A. and Ganapathy, C., 2002; Teo et al., 2006; Basri, H. B et al., 1999). In addition, the main advantage of using waste in nature and converting them to useful material such as LWC will lead to environmental conservation and reduce pollution. This is because this waste is expected to increase as the nation's quest for renewable energy from biological sources increases. This waste pollutes the vicinity where it is deposited and constitutes an environmental nuisance. There is an enduring need to obliterate this waste for a more conducive habitation. This can be achieved by exploring an avenue of putting the waste into beneficial alternative uses. One of the ways to do this is to use the waste as an aggregate in concrete. This would ensure resource preservation by reducing the depletion of natural resources from rock fragments, which are normally crushed to obtain aggregate for construction works. So, the benefit of using POC lightweight aggregate is basically to reduce the dead load of concrete structure without any loss in the strength of the structure. This is possible since lightweight concrete can reduce the dead load by as much as 35% and still provide the structure's strength (Omar and Roslli, 2002). Therefore, the reduction of the dead load of the structure will lead to a decrease in the cost of the construction which is an important advantage of POC over normal weight concrete (NWC). In addition, there was a problem that needed to be resolved, which the researcher faced at the beginning when he wanted to do the Design of Experiments (DOE), especially in the field of structural engineering. In DOE, there is sometimes more than one variable that cannot be determined accurately, or there may be a variable which is more influential than the other, and a suitable number of samples has to be specified. This paper will help to choose a suitable number of samples for studying by using the Box-Behnken Design.

2. EXPERIMENTAL PROCEDURE

2.1 Response Model

The RSM explores the relationships between several explanatory variables and one or more response variables (Basim A. Khidhir and Bashir Mohamed; 2011). The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. RSM is a combination of experimental and regression analysis, and statistical inferences. The concept of a response surface involves a dependent variable y called the response variable and several independent variables x_1, x_2, . . .,x_k (Basim A. Khidhir and Bashir Mohamed; 2009; J. Grum and J. M, 2004; G.E.P. Box and K.P. Wilson, 1951)

$$y = f(x_1; x_2; \dots ; x_k) \tag{1}$$

The goal is to optimize the response variable y. It is assumed that the independent variables are continuous and controllable by the experimenter with negligible error. The response or the dependent variable is assumed to be a random variable. In RC beams with web openings, it is necessary to find a suitable combination of depth of beam ($x_1 = D$), location of opening ($x_2 = L$), and length of opening ($x_3 = W$), that optimizes response. The observed response y as a function of the D, L and W, can be written as:

$$y = f(x_1, x_2, x_3) + \varepsilon \tag{2}$$

Where ε : Error observed in the response y

Usually a low order polynomial (first-order and second-order) in some regions of the independent variables is employed. The first-order model is expressed as:

$$y = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \varepsilon \tag{3}$$

For the relationship between the response variable y for example, the ultimate load and independent variables in our case are usually unknown. In general, the low-order polynomial model is used to describe the response surface. A polynomial model is usually a sufficient approximation in a small regain of the response surface. Therefore, depending on the approximation of unknown function f , either the first order or second- order model are employed (Teychenne, D.C.et al., 1988)

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \tag{4}$$

Where y is the response, x_1= *Depth of beam* (*D*), x_2 = *Location* of openings (*L*), x_3 = *Length of openings* (*W*). β_0 = C and β_1, β_2 andβ_3, are the model parameters.

The second-order model is flexible because it can take a variety of functional forms and approximates the response surface locally. Therefore, this model is usually a good estimation of the true response surface. In this study, the second order model has been utilized:

$$y = \beta_o + \sum_{j-1}^{q} \beta_j x_j + \sum_{i-1}^{q} \beta_{jj} x_j^2 + \sum \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon \tag{5}$$

$$= \beta_o + x_i' \beta + x_i' \beta x_i + \varepsilon_{ij} \tag{6}$$

Where $x_i = (x_{1i}, x_{2i}, \dots, x_{iq}), \beta = (\beta_1, \beta_2, \dots, \beta_q)$

2.2 Concrete Materials and Mix Proportion

POC lightweight aggregate has been selected as fine and course aggregate (100%) rather than NWC in LWC mix without any admixture for producing lightweight reinforced concrete beams with web openings. The clinker, which was produced from local sources, is an unprocessed by- product material from palm oil clinker industrial. Initially clinkers were taken in a form of hard porous lumps. The clinker was from the bottom part of the boiler after the finishing of oil extraction process and the clinker needs to be crushed to a smaller size. The sieve analysis of the POC was found according to the requirement of (ASTM C136) which stated that any aggregates passing the 5 mm sieve size are classified as fine aggregates. Also, the coarse aggregate fractions are obtained by taking particles passing a particular maximum size

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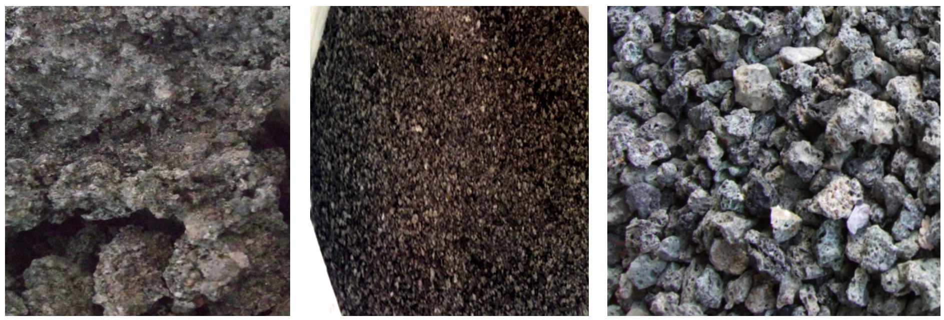
(14 mm) but retained on a 5 mm sieve size. A coarse lightweight aggregate of structural coarse class has particle gradation in the range 14 mm to 5 mm. The clinker was sieved and soaked in the water to achieve the Saturated Surface Dray (SSD) condition of aggregate by using POC, and to remove the harmful substances from the clinker. The strength and the workability of the mix were also expected to be enhanced. The POC material is as shown in Figure 2.



(a) (b) (c)

Figure 2: Lump Palm Oil Clinker

Three cylindrical (150 mm diameter and 300 mm height) compressive strength tests at an age of 28 days produced compressive strengths of 25.4 MPa, which is higher than the minimum required strength of 17 MPa, for structural concrete recommended by ASTM C330. The palm oil clinker is an industrial waste by product of palm oil kernel; many tests have been conducted to obtain some basic properties of these lightweight aggregates. The results of the tests were then checked with appropriate standards to ensure the suitability of clinker aggregates to be used in lightweight concrete mixture (Abdullahi et al, 2008). The ingredients of the POC are shown in Table 1.

Table 1: The ingredients of the POC

POC Contents	Unite	POC as LWC
Cement	Kg/m^3	500
Coarse aggregate of POC	Kg/m^3	343.9
Fine aggregate of POC	Kg/m^3	739.3
Water /cement ratio	-	0.44
Water	Kg/m^3	220
Additional water to coarse aggregate to reach SSD	Kg/m^3	105.6
Additional water to fine aggregate to reach SSD	Kg/m^3	18.5

2.3 Lightweight POC RC beams with web openings: Instruments and Testing

Fifteen specimens of full scale lightweight palm oil clinker beams with web openings were fabricated and tested. All the beams were simply supported and they were subjected to a two point load. All beams tested had a rectangular cross section with a total length of 2400 mm. The width of beams, depth of openings and shear span of beams were kept constant and are shown in Figure 3. The selected beams differed in their depths (D), location of openings (L) and length of openings (W). The bottom reinforcement provided for all beams consist of three 16 mm diameter bars, and the top reinforcement consist of two bars of 12 mm diameter. All tested beams were have vertical stirrups of 8 mm diameter. The rectangular openings had vertical closely spaced stirrups of diameter 8 mm around its openings as corner reinforcement. Lightweight palm oil clinker reinforced concrete beams with web openings have been tested with different boundary conditions to investigate all the various parameters mentioned above. The fifteen beam specimens were obtained based on an analysis using RSM. All the specimens were prepared for experimental tests to evaluate the effect of the ultimate load on depth of beams, location of openings and length of openings. The details of beam and its loading arrangement of a selected specimen are shown in Figure 3.

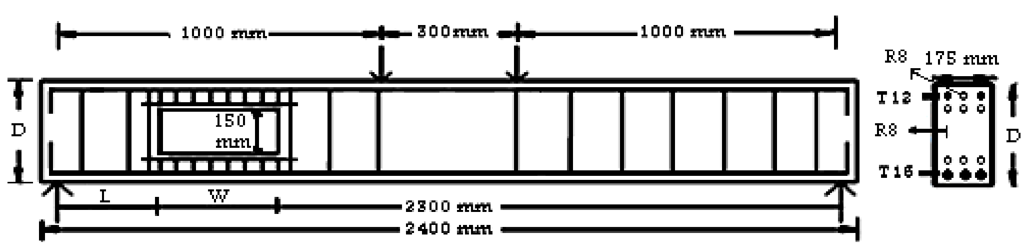


Figure 3: Beams details and loading arrangement

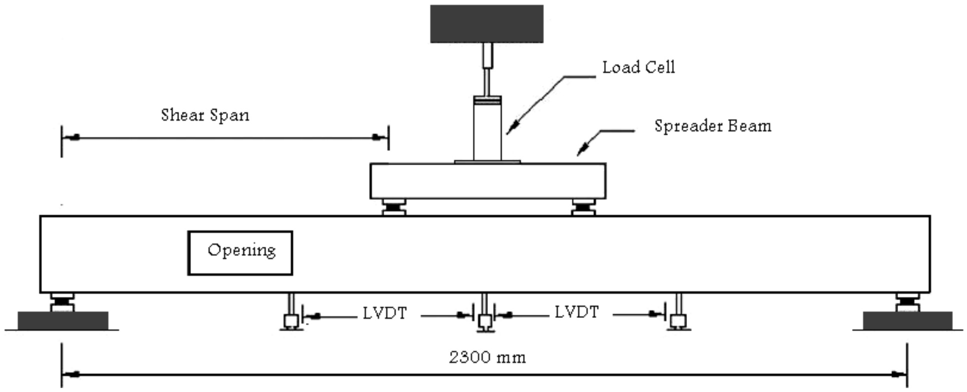


Figure 4: Beam instrumentations

Three linear vertical displacement transducers (LVDT) were used to measure vertical displacement of the beam at web opening, at mid-span as shown in the Figure 4. The loads were applied incrementally in a load control manner up to failure.

3. RESULTS AND DISCUSSION

3.1 Case Study 1

In order to study and model the effect of the ultimate load, the three kinds of design parameters mentioned above: (D), (L) and (W) are chosen as the tuned variables. Table 2 illustrates the levels of variables and coding identifications used in this case. Table 3 shows the necessary Coded values for the application of this design for three levels proposed by RSM using Minitab Software.

Table 2: Suggested values of corresponding levels

Level / Coding	Low	Medium	High
	-1	0	1
D	350	400	450
L	275	325	375
W	250	325	400

The number of experiments and the corresponding levels proposed by Minitab Software are shown in Table 3.

Table 3: Experiments and the corresponding levels proposed by Minitab

Run order	D	L	W
1	0	-1	1
2	1	1	0
3	0	0	0
4	0	1	-1
5	1	-1	0
6	0	1	1
7	1	0	-1
8	0	-1	-1
9	1	0	1
10	0	0	0
11	-1	1	0
12	0	0	0
13	-1	-1	0
14	-1	0	-1
15	-1	0	1

3.1.1 Analysis of Results

The experimenta1 design used in this work comprises three factors; depth of beams, location of openings and length of openings. The results of 15 numbered specimens of LWPOC RC beams which were obtained from RSM and experimental data are shown in Table 4.

Table 4: Predicted ultimate load data vs. Experimental ultimate load

Run order	D (mm)	L (mm)	W (mm)	Ultimate Load (Experimental) (kN)	Ultimate load (Predicted) (kN)
1	400	275	400	158.2	158.5
2	450	375	325	180.5	181.7
3	400	325	325	162.9	162.6
4	400	375	250	169.8	169.5
5	450	275	325	192.7	193.0
6	400	375	400	147.8	147.2
7	450	325	250	199.4	198.8
8	400	275	250	174.7	175.2
9	450	325	400	176.3	175.9
10	400	325	325	162.9	162.6
11	350	375	325	135.4	135.0
12	400	325	325	162.9	162.6
13	350	275	325	141.9	140.6
14	350	325	250	145.1	146.0
15	350	325	400	128.6	129.8

The process considered three input variables [depth of the beam (D), location of opening (L), and length of opening (W)] to develop a model from the experimental results using RSM. The polynomial model used is defined in Eq.7, (Sadam et al, 2011).

3.1.2 Model for Ultimate Load

Several polynomial model for ultimate load prediction were considered. This model includes a full quadratic. The analysis was conducted at a 95% confidence interval and a 5% level of significance.

3.1.3 Full Quadratic Model (Second-order Model) for Ultimate Load

The full quadratic model for ultimate load is given by the following equations:

$$\textit{Ultimate load} = -135 + 0.823\,D + 0.262\,L + 0.165\,W - 0.000570\,D*L - 0.000440\,D*W - 0.000367\,L*W \quad (7)$$

The process considered three input variables [depth of the beam (D), location of openings (L), and length of opening (W)] in order to develop models from the experimental results and RSM. The polynomial model has been used as defined by Eq. 7 for ultimate load.

3.2 Case Study 2

3.2.1 Verification for Modeling of Ultimate Load of POC RC beams with Web Opening

Additional specimen was designed on the same scale as LWPOC RC beams with web openings. They were fabricated and tested, but not before taking on board the new dimensions of the variables or (Factors), that is, the depth of the beam (D) is equal to 375 mm, the location of an opening (L) is equal to 225 mm and the length of an opening (W) is equal to 360. These were the compensated values of the variables in Eqs. 7 were obtained based on an analysis using RSM to compare with the values of those obtained from the experimental work.

3.2.2 Model Check

A model of the ultimate load will compensate the values of the new dimensions in Eq. 7 of three factors as mentioned above. This will verify the model of ultimate load obtained. The details of the compensated values of three factors are as found below:

Ultimate load = - 135 + 0.823 (**375**) + 0.262 (**225**) + 0.165 (**360**) - 0.000570 (**375*****225**) - 0.000440 (**375*****360**) - 0.000367 (**225*****360**) = **154.75** kN

The result of the ultimate load obtained from the experimental test equal to **148.3 kN** means it is clear that the predicated values obtained via the response surface method are in good agreement with the data taken from the experimental test within an acceptable percentage of error. This indicates that the obtained model is useful in predicting values of ultimate load.

In order to judge the accuracy of the prediction model, the percentage deviation ($\emptyset i_i$) and the average percentage deviation ($\overline{\emptyset}$) were used as defined below:

$$\emptyset_i = \frac{|Ra_{exp} - Ra_{pre}|}{Ra_{exp}} x100\% \quad (8)$$

Where $\emptyset_i$= Percentage deviation of a single experiment data

Ra_{exp}= actual Ra by Experimental work

Ra_{pre}= predicted Ra generated by a multiple regression equation.

$$\overline{\emptyset} = \frac{\sum_{i=1}^{n} \emptyset_i}{n} \quad (9)$$

Where $\overline{\emptyset}$**:** average percentage deviation of all experiments,
n: the size of sample data

This method tests the average percentage deviation of the result of experimental work and predicted result as well as its ability to evaluate the prediction of this model. The regression model could predict the ultimate load from experimental data sets with an acceptable error percentage is equal to 4.34%.

4. CONCLUSIONS

In the present research, the second-order model based on RSM is developed to predict and verify the ultimate load of LWPOC RC beams with web openings. The results shows the developed model is sufficient to predict the ultimate load with good adaptability and high accuracy, Moreover, the advantage of this research lies in the fact that it can be developed for use in the future in order to provide the expected ultimate load of LWPOC RC beams with web openings for designers in cases where he or she wishes to assess the expected ultimate load of a particular design embarking on the implementation and final design phases. Additionally, the verification for model of ultimate load has proved that the designer or experimenter can depend on the models obtained from statistical programs using RSM to estimate the values or data of experimental work within an acceptable percentage of error. To the best of the researcher's knowledge, there is no research which has sought to identify the use of POC RC beams with web openings nor has any study attempted to obtain the prediction data of ultimate load of LWPOC RC beams with web openings.

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