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Statistical Modelling for Verification of Deflection for Lightweight Reinforced Concrete Beams with Openings

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Abstract **-This paper suggests a model for verification of deflection of Lightweight concrete (LWC) using Palm Oil Clinker (LWPOC) reinforced concrete (RC) beams with openings. The suggested model is developed to predict and verify the deflection using the Response Surface Methodology (RSM). The deflection has been investigated against three parameters, namely beams depth, openings location respect to support, and openings length of LWPOC RC beams. The results show that the scientifically advanced model has excellent adaptability and high accuracy.**

Keywords: **LWPOC, RC beams, openings, RSM, Model, Deflection**

I. Introduction

1-8 Structural members are frequently confronted with the problem of having to provide openings like passageway for usefulness tubes for main services as telephone and electricity cables. Obviously if openings through RC beams or girders can be made for tubes without sacrificing structural integrity. The elimination of dead spaces in false ceilings of multistory buildings can allow reduction in the height of the building, thus reducing the amount of material running from floor to floor which could significantly cut construction costs. Many types of researches for RC beam with openings using Normal Weight Concrete. Currently, the world is moving towards the development of a new type of concrete that uses green technology to limit pollution and the cost of construction. This research sheds light on the structural engineering aspect of this development by using a new lightweight concrete (LWC) obtained from the waste of materials, called LWPOC. LWC is accepted as being eco- friendly. It has a lower density compared with normal weight concrete and thus reduces the cost of construction9. Moreover, the construction materials technologies and building practice have developed. The Construction industry is the biggest energy consuming part. With growing urbanization, natural resources are being used in the construction. Environmental conscious buildings design has become significant. The concept of green building is the construction of energy efficient construction buildings which result in reduced water and air pollution, less water consumption, and increased user productivity. The consciousness of green building has begun and with building industry poised for a big growth, green building industry would be a mantra of the construction building industry in future. Going green is a prospective building technology for the environmentally harmonious cities. Moreover, the primary advantage of using waste in nature and converting them to useful material such as (LWC) will lead to environmental conservation and decrease pollution. Moreover, (LWC) has been used since 2000 years ago, an early example being a 44- meter dome for a Roman building. Clinker concrete, a form of lightweight concrete, was in use in the United Kingdom and in the USA in the late nineteenth century. It was also used for the extension of a British museum in 1907. Moreover, there was a problem that needed to be resolved, which the experimenter faced at the starting when the researcher or experimenter wanted to do the Experiments Design, especially in the field of structural engineering. In Design of Experiments (DOE), there is occasionally more than one variable that cannot be determined precisely, or there may be a variable which is more effective than the other, and a suitable number of samples have to be specified. Moreover, the results that obtained from experimental work are compared with predicted data obtained from RSM using Minitab Software. In addition, in this research will develop three statistical models using RSM.

II. Statistical Method for Design of Experiments

A. Box-Behnken Design (BBD)

10 two authors suggested how to choose points from full factorial. This design is more effective and saving than full factorial design. Because (BBD) have lower design points, they are lower costly comparing with other approaches. (BBD) is appropriate for experiments with a numerous number of factors within a short time and a low cost. BBD is experimental design for RSM. The RSM is a statistical method beneficial for evolving and verifying models 11-12. RSM is used to verify this model. Following this, the precision of the RSM is validated versus the experimental data. The LWPOC RC beams design include three significant factors namely beams depth (D), location of openings respect to support (L) and openings length (W).

The development of BBD for three variables (Factors) can be as shown in Figure 1.

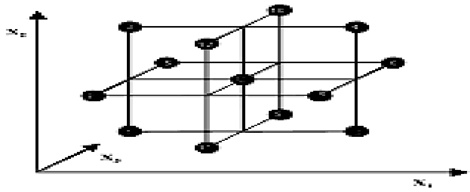

FIGURE 1: BBD FOR THREE VARIABLES (FACTORS)

B. Fine and Course Lightweight Aggregate of POC

POC has been selected as fine and course aggregate (100%). This is instead of normal weight concrete in concrete mixes which is often used for producing L3WPOC RC beam with web openings. The solid clinker, which was produced from local sources, is an unprocessed by- product material from an industrial palm oil clinker. Initially, clinkers are taken in the form of hard porous lumps. The clinker is from the bottom part of the boiler after the completion of the oil extraction process and is crushed to a smaller size using a compactor machine. After being crushed, the aggregate is passed through a 5.0 mm sieve, so as to qualify as fine aggregate. In addition, the coarse aggregate fractions are acquired by taking particles which surpass a maximum size of 14 mm but are retained on a 5 mm sieve. A coarse lightweight aggregate of the structural coarse class has particle gradation in the range 14 mm to 5 mm and is recommended in [13] for concrete making. Finally, during this research the clinker is soaked in water for a long time to achieve the Saturated Surface Dray (SSD) condition of aggregate, thus the POC does not absorb water from the mix design. Consequently, the strength and the workability of the mix are enhanced. The POC lumps are shown in Figure 2 and Figures 3 shows the processed fine and coarse POC. Three cylindrical compressive strength tests at an age of 28 days produced compressive strengths of 25.4 MPa. The ingredients of the POC are shown in Table 1.

FIGURE 2: LUMP POC

TABLE 1: THE INGREDIENTS OF THE 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

FIGURE 3: FINE AND COARSE POC AFTER WASHING

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C. Lightweight POC RC beams with web openings: Instruments and Testing

The selected RC beams differed in their depths (D), location of openings (L) and length of openings (W). The bottom reinforcement provided for all RC beams consist of three 16 mm diameter bars, and the top reinforcement consist of two bars of 12 mm diameter. All tested RC beams have vertical stirrups of 8 mm diameter. The rectangular openings had vertical closely spaced stirrups of diameter 8 mm around its opening as corner reinforcement. All of the beams are simply supported and are subjected to a two point load. All beams tested have a rectangular cross section with a length of 2.40 m. The fifteen beams specimens are obtained based on an analysis using RSM. All the specimens are prepared for experimental tests to evaluate the effect of the deflection on the D, L and W. The details of LWPOC RC beam and its loading arrangement of a selected specimen are shown in Figure 4.

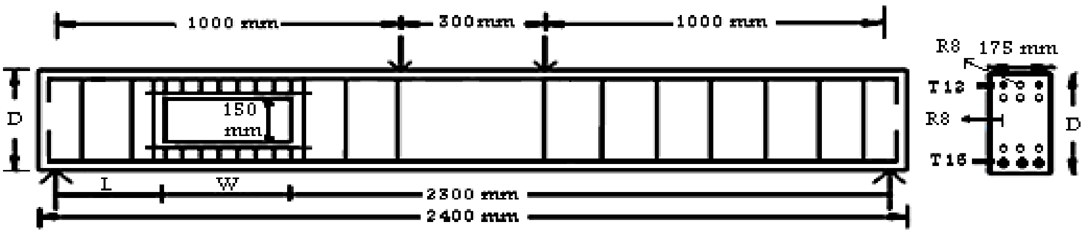

Figure 4: RC Beams details and loading arrangement

Three vertical displacement transducers (LVDT) were used to measure vertical displacement of the LWPOC RC beam at web opening, at mid-span as shown in Figure5. The loads were applied incrementally in a load control technique up to failure.

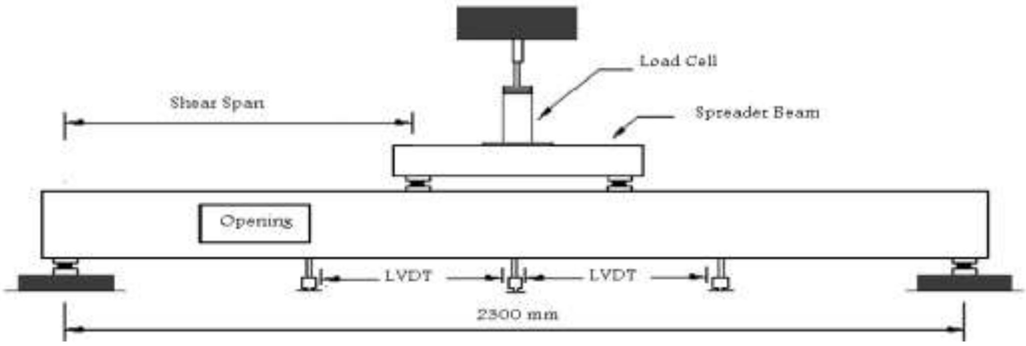

Figure 5: Beam with web opening instrumentations

III. Discussion of Data

A. First Case

In order to model the deflection influence, the factors mentioned above: (D), (L) (W) are chosen as the tuned variables. The necessary Coded values for the application of this design for three levels proposed by RSM using statistical Software are shown in Table 2.

Table 2: Suggested values of corresponding levels

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

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I. RESULTS ANALYSIS

The experimental design used in this work comprises three factors; (D), (L) and (W). The results of fifteen numbered specimens of LWPOC RC beams which were obtained from RSM and experimental data are shown in Table 3 . Moreover, the main effect plot for experimental test and RSM showed that the deflection was influenced by the (D), (L) and (W) as well as their interactions with the regression model. The analysis began with interaction plots of deflection with all parameters those obtained from experimental work and RSM are shown in Figures 6 and Figures7.The (D), (L) and (W) are very significant parameters which were used to verify the deflection in the full quadratic model. The results between experimental test and RSM are very close in terms of accuracy. Furthermore, the main effects plot for deflection that obtained from experimental work and RSM as shown in Figure 8 and Figure 9, respectively.

TABLE 3: PREDICTED DEFLECTION DATA VS. EXPERIMENTAL DEFLECTION PROPOSED BY MINITAB SOFTWARE

Run order	D (mm)	L (mm)	W (mm)	Deflection (Experimental) (mm)	Deflection (Predicted) (mm)
1	400	275	400	10.33	10.48
2	450	375	325	7.51	7.54
3	400	325	325	9.74	9.90
4	400	375	250	9.20	9.32
5	450	275	325	6.82	6.75
6	400	375	400	11.62	11.27
7	450	325	250	6.30	6.17
8	400	275	250	8.59	8.53
9	450	325	400	8.14	8.12
10	400	325	325	9.74	9.90
11	350	375	325	13.01	13.05
12	400	325	325	9.74	9.90
13	350	275	325	12.41	12.26
14	350	325	250	11.80	11.68
15	350	325	400	13.60	13.63

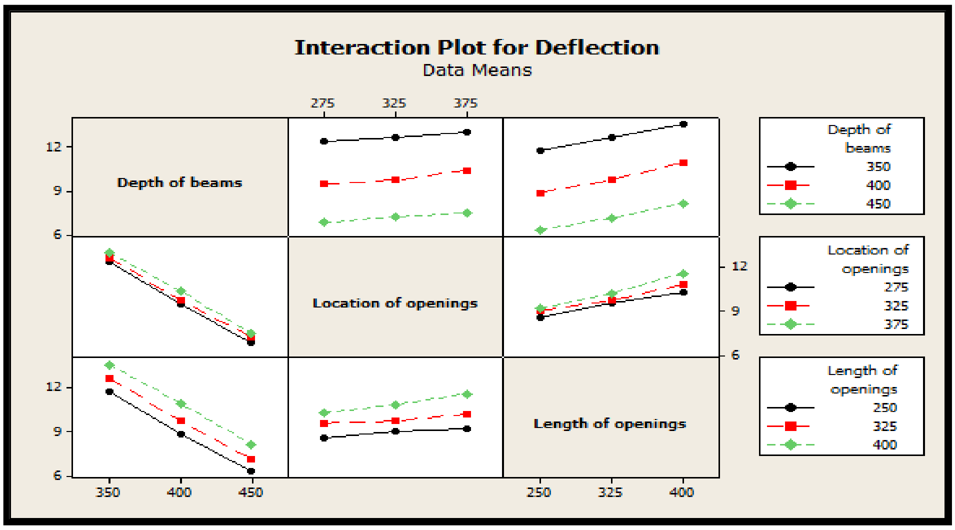

FIGURE 6: THE INTERACTION PLOT FOR DEFLECTION (EXPERIMENTAL WORK)

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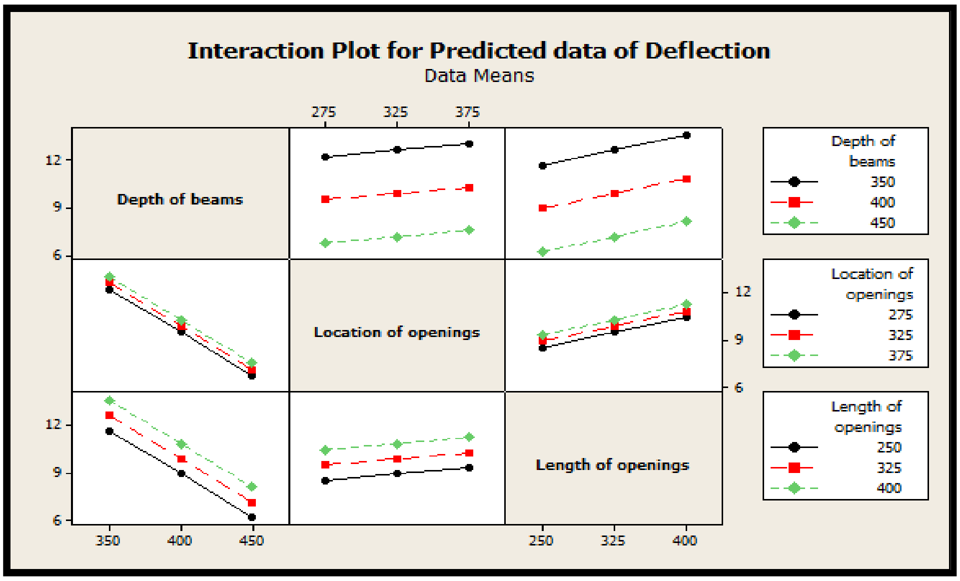

FIGURE 7: THE INTERACTION PLOT FOR DEFLECTION (RSM)

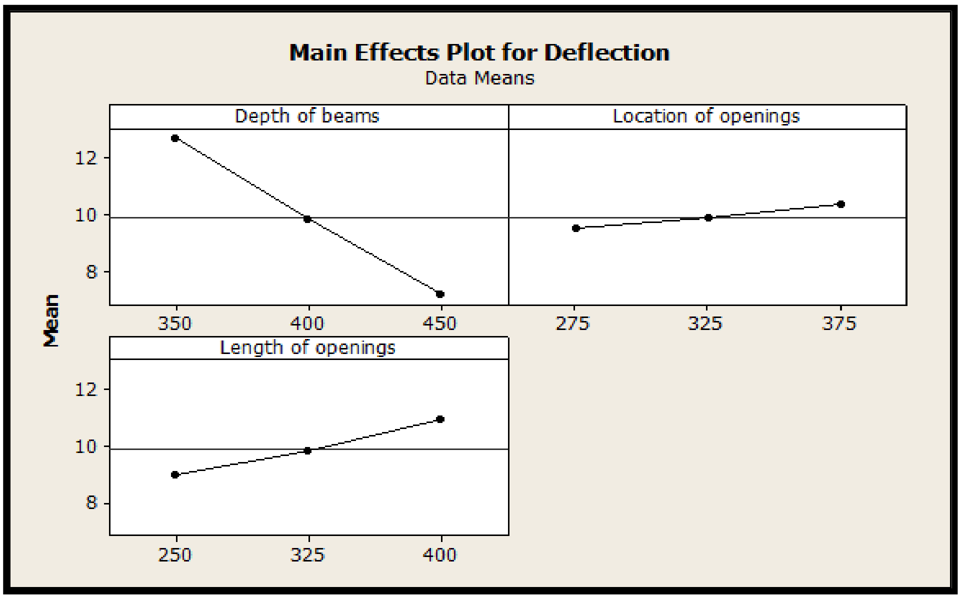

FIGURE 8: THE MAIN EFFECT FOR DEFLECTION (EXPERIMENTAL WORK)

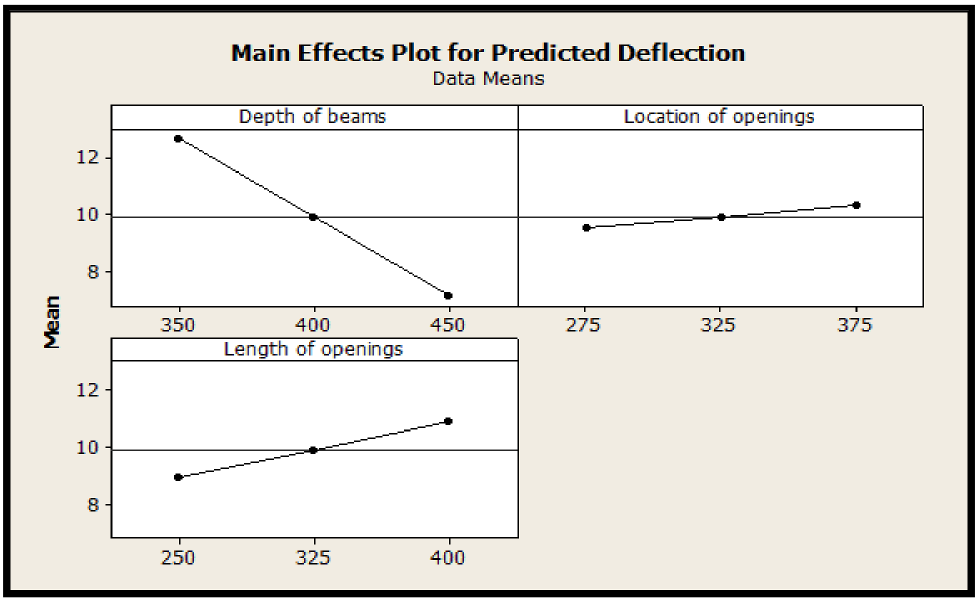

FIGURE 9: THE MAIN EFFECT FOR DEFLECTION (RSM)

II. DEFLECTION MODEL

Model for deflection prediction was considered. This model includes a full quadratic. The analysis was conducted at a 95% confidence interval and a 5% level of significance.

III. FULL QUADRATIC MODEL (SECOND-ORDER MODEL) FOR DEFLECTION

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

$$\text{Deflection} = 25.1 - 0.0551\,D + 0.00796\,L + 0.0130\,W \qquad (3)$$

The process considered three input variables (D), (L), and (W) in order to develop model from the experimental results and RSM. The polynomial model has been used as defined by Equation 3, for deflection. The regression output for the full quadratic (second –order model) of the modeling of deflection is as shown in Table 4 and Table 5.

TABLE 4: REGRESSION OUTPUT FOR DEFLECTION

Predictor	Coef	SE Coef	T	P
Constant	25.1333	0.6581	38.19	0.000
Depth of beams	-0.055095	0.001175	-46.90	0.000
Location of openings	0.007963	0.001175	6.78	0.000
Length of openings	0.0129883	0.0007831	16.59	0.000

S = 0.166124   R-Sq = 99.6%   R-Sq(adj) = 99.4%

TABLE 5: ANALYSIS-OF-VARIANCE FOR DEFLECTION

Source	DF	SS	MS	F	P
Regression	3	69.569	23.190	840.28	0.000
Residual Error	11	0.304	0.028		
Total	14	69.872			

B. SECOND CASE

I. VERIFICATION OF DEFLECTION OF POC RC BEAMS WITH WEB OPENING

Additional sample was designed on the same scale as LWPOC RC beams with web openings. it was fabricated and tested, but not before taking on board the new dimensions of the factors or (Variables), that is, (D) is equal to 375 mm, (L) is equal to 225 mm and (W) is equal to 360. These were the compensated values of the variables in Equation7 were obtained based on an analysis using experimental test to compare with the values of those obtained from the RSM.

II. MODEL CHECK

A model of the deflection will compensate the values of the new dimensions in Equation 3 of three factors as mentioned above. This will verify the model of deflection obtained. The details of the compensated values of three factors are as found below:

Deflection = 25.1 **-** 0.0551 **(375**) + 0.00796 (**225**) + 0.0130 (**360**) = **10.9** mm

The result of the deflection obtained from the experimental test equal to 11.57 mm, means it is clear that the predicated values obtained via the RSM are in a perfect acceptance with the results taken from the experimental test within an acceptable error percentage. These denote that the acquired model is useful in predicting values of deflection.

IV**.** CONCLUSIONS

The RSM test suggests that the full quadratic model is capable of explaining the data and the factors used in this research are very significant, which leads to an increase in the values of R-sq and adjusted R-sq. The RSM proved to be a good method to design the experiment and to determine the appropriate number of samples which are used in the experimental test of LWPOC RC beams with web openings and achieve accurate results. In addition, this method saves time and cost. Finally, the verification for models of deflection has proved that the experimenter can depend on the model obtained from statistical software using RSM to estimate the values or results of experimental work within an acceptable percentage of error. To the best of the researcher's knowledge, there is no research has sought to identify the use of POC RC beams with web openings nor has any study attempted to obtain the prediction results of deflection of LWPOC RC beams with web openings.

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