# MIX DESIGN WITH RESPONSE SURFACE METHODOLOGY TO OPTIMIZE THE FLEXURAL STRENGTH OF CONCRETE

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## ABSTRACT

This paper presents a technical proposal for the application of experimental designs in the construction processes of civil works, specifically in the manufacture of concrete for rigid pavements. Currently is still does not apply these technological advances, or any application of research methods that allows optimizing processes to more satisfactory levels, despite the advantages and benefits they provide in terms of achieving unexpected performance and significant savings of component materials. The experimental design model is a classic statistical model whose objective is to determine if the independent factors influence in a variable of interest in this case the modulus of breakage of the concrete or in another important factor, during the bending test. The answer surface methodology is based on the experimentation in three stages, the results achieved allow locating an optimal area where the adjusted values lead to reduced consumption of them and expanding the strength of the concrete.



## KEYWORDS

Concrete, Experimental method, Optimization, Resistance, Flexural strength, Rigid pavements.



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# 1. INTRODUCTION

The rigid pavements made based on concrete, present in their vast majority the presence of structural and superficial fissures, these have become a problem regarding its functionality and the useful life in terms of the level of service to the vehicles that circulate in these routes.

The reasons are many; among the most relevant we can name the mix design for concrete, the method of making the "cloths", the materials used, the quantity or proportion of the components, etc., the latter is constitutes the objective of the investigation. It is observed that the method used at the present time are the conventional ones that do not allow the necessary adjustments to be made to the materials and their performance in order to achieve optimum levels in terms of dosage and as a product, greater resistance to bending called the Break Module (MR).

The manufacturing method is frequently that of the American Concrete Institute (ACI), as the dosage is very rigid and closed, it does not allow modifications to be made to the components, such as cement, aggregate, water, additives, etc. For this, it is necessary to resort to other methods that give the possibility of manipulating these independent variables and with the hypothesis of reaching optimum levels of the mechanical properties of the concrete. For this it is necessary to use the experimental designs (widely used in other areas of engineering) that, based on a practical methodology and the use of logical reasoning, it is possible to adjust both the quantity of materials and the resistance to flexion even more optimal, is possible use algortihms for calculations as Sánchez *et al.* (2020) and Soto *et al.* (2020).

Deterministic simulation models have the characteristic of being a technique for solving practical problems (Levy *et al.*, 2020), such as an overall change of variables over time. Experimental models are an approximation to the real system. From the above, there is a need to repeat multiple simulation runs, consequently, its use in an investigation should be planned as a series of experiments that lead to significant interpretations of the relationships of interest (Huapaya, Rodriguez & Esenarro, 2020).


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The response surface methodology (MSR) was used in this investigation. This modeling methodology is a holistic approach that allows us to postulate the form of the objective function, update and limit the values of the parameters, as well as explore and approach the region close to the optimal estimate.

## 2. METHOD

The Response Surface Methodology (MSR) is the tool used to achieve the proposed objectives, for which reason it was necessary to experiment sequentially in the stages it comprises until the desired level of improvement is found. In this case, after a first experimental stage (selection of influential variables) it was necessary to move the experimental region (move from place) in a suitable direction, or to explore the initial experimental region in more detail (see Figure 1). The way to do both is part of the so-called Response Surface Methodology (MSR).

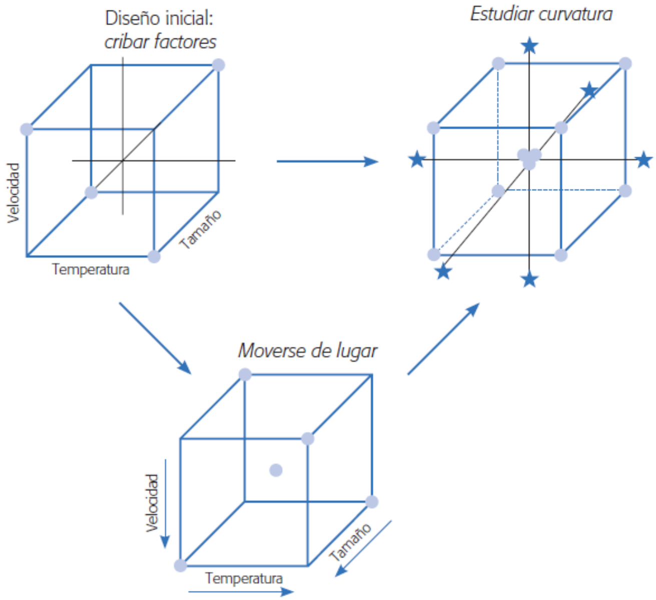


**Figure 1.** Basic actions of the MSR. **Source:** (Gutiérrez-Pulido & De la Vara, 2008).


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## 2.1. SIEVING OR CLASSIFICATION

In this first optimization stage, we identify the controllable variables that can significantly influence the process responses (fine aggregate, cement) and "eliminate" those that were not significant for a good economic orientation of the process, because it reduces the number of variables and Experimental tests in the later stages of optimization (Figure 2). When controllable variables range from low to high, they affect expected responses. For our case, we use the first-order factorial design.

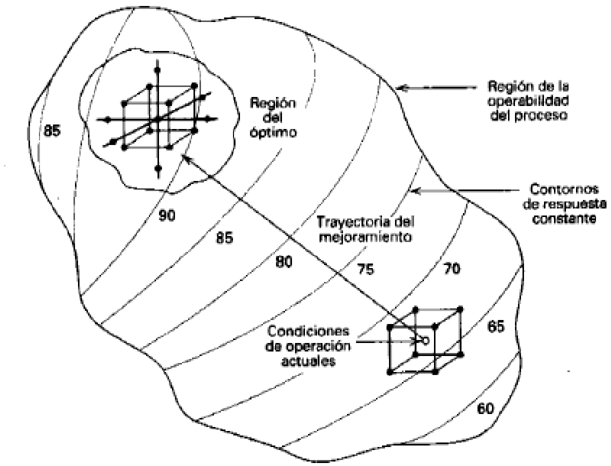


**Figure 2.** The sequence of the MSR. **Source:** (Montgomery & Runger, 1996).

## 2.2. ESCALATION

Having located the optimal region, and observing that it is still far from the initial experiments (sieving), then was initiated the second stage called "scaling", which consisted of successively climbing towards the optimal region until reaching it (Figure 3), to achieve for this objective, we use the indirect method of ascending slopes in two periods. The method of the steepest ascent is the one that allowed us to go to the zone of the maximum increase of the response, according to formula (1).


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$$\hat{Y} = \hat{\beta} + \sum_{i=1}^{k} \hat{\beta}_i x_i \qquad (1)$$

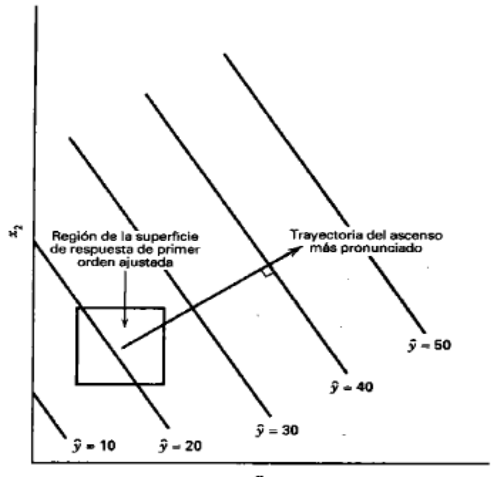


**Figure 3.** The sequence of the MSR. **Source:** (Montgomery & Runger, 1996).

## 2.3. FINAL OPTIMIZATION

When locating ourselves in the previous stages of the experimental region that contains the optimum, in this region, the second-order effects were more significant in absolute value than the first-order effects; this region is appropriately described by second-order mathematical models as shown in equation (2). In this case, we use the hexagonal design of Figure 4. After closing the optimal region, in this stage, the second-order effects are more significant, for which we use the formula.

$$Y = b_0 + \sum_{i=1} b_i x_i + \sum_{i=1} b_{ii} x_i^2 + \sum_{i=1} \sum_{\substack{j=2 \\ j}} b_{ij} x_i x_j + \varepsilon \qquad (2)$$

Response variable Unknown parameters Random error


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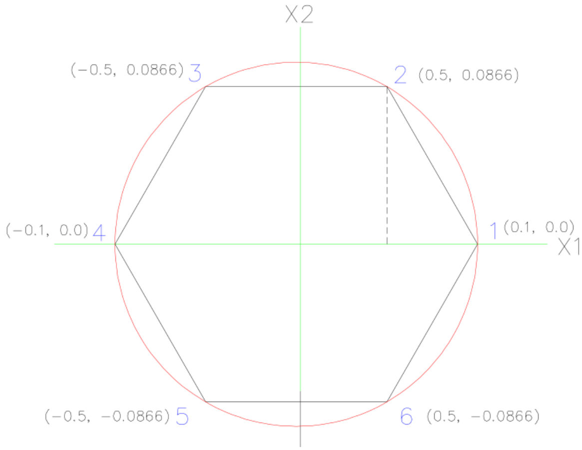


**Figure 4.** Hexagonal design structure with coded values.

# 3. RESULTS

The beam bending tests carried out at 4, 14, 21, and 28 days provide us with information on the modulus of rupture. It is observed that the mean (41.37) of the module of the ten designs with variable factors concerning the mean of the standard design (36.40) differs in 4.97, the design that grants the highest resistance is the second (44.82) at 28 days of maturation. And for the pattern design, it has a difference of 8.42.

**Table 1.** Details of the control.

| | | | | | Beams 30x30x50 | | | | | | Patron | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date Empty | 06/01/18 | 06/01/18 | 06/01/18 | 07/01/18 | 07/01/18 | 07/01/18 | 07/01/17 | 08/01/18 | 08/01/18 | 08/01/18 | 07/01/18 | **Mean** |
| Breakdate Date | 03/02/2018 | 03/02/2018 | 03/02/2018 | 04/02/2018 | 04/02/2018 | 04/02/2018 | 04/02/2017 | 05/02/2018 | 05/02/2018 | 05/02/2018 | 04/02/2018 | |
| READING (Kn / Cm²) | 33.73 | 35.21 | 32.62 | 31.07 | 31.85 | 35.1 | 30.59 | 35.09 | 30.4 | 32.05 | 28.59 | 32.39 |
| READING P (Kg / Cm²) | 3439.45 | 3590.36 | 3326.26 | 3168.21 | 3247.74 | 3579.15 | 3119.26 | 3578.13 | 3099.89 | 3268.14 | 2915.32 | 3302.90 |
| FREE LIGHT L (Cm) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| AVERAGE WIDTH B (Cm) | 15.30 | 15.40 | 15.20 | 15.40 | 15.50 | 15.40 | 15.30 | 15.50 | 15.40 | 15.30 | 15.60 | 15.39 |
| AVERAGE HEIGHT D (Cm) | 15.50 | 15.30 | 15.30 | 15.50 | 15.30 | 15.40 | 15.20 | 15.40 | 15.60 | 15.30 | 15.20 | 15.36 |
| Edge Distance | 29 | 27 | 17.5 | 24.8 | 26.7 | 24.9 | 17.7 | 20.1 | 29.4 | 25.5 | 28 | 24.6 |
| Distance In middle Third | 11.5 | 9.5 | 0 | 7.3 | 9.2 | 7.4 | 0.2 | 2.6 | 11.9 | 8 | 10.5 | 7.1 |
| BREAKDOWN M(Kg / Cm²) | 42.11 | 44.82 | 42.07 | 38.53 | 40.28 | 44.10 | 39.71 | 43.80 | 37.22 | 41.06 | 36.40 | 41.37 |

**Source:** authors' own elaboration.


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The optimal conditions of the controllable, independent variables are Cement = 617.95 kg / m³ and the fine aggregate = 1816.44 kg / m³, replacing these values obtained in the coded mathematical model, the maximum strength of the concrete is obtained, which would reach 93%. By using the MINITAB version 16 software, we elaborated on the optimization graphs for the flexural resistance of rigid pavement concrete.

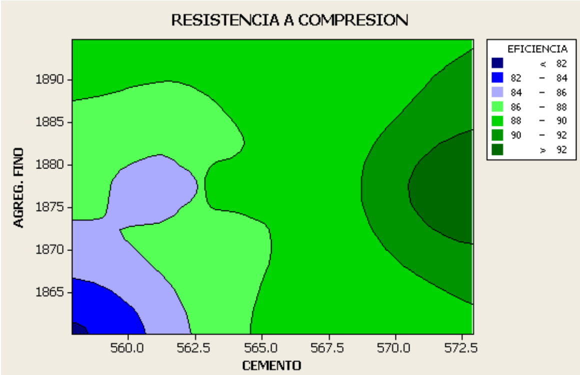


**Figure 4.** Optimized area for the controlled factors of strength to compressive. **Source:** authors' own elaboration.

A curve system is observed in the graph, and due to the color distribution, the maximum efficiency is achieved with the maximum level of cement and with a standard level of fine aggregate (dark green color).

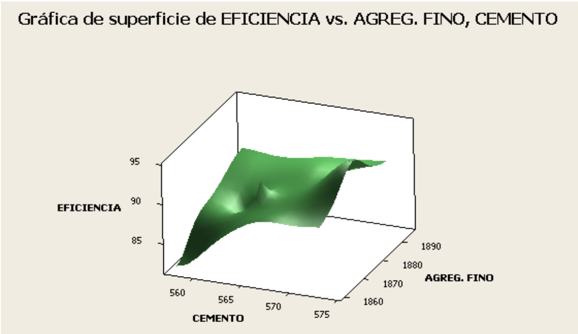


**Figure 5.** The efficiency of the optimization process regarding fine aggregate and cement. **Source:** authors' own elaboration.


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In the quadratic effect spatial graph, the contour system is notorious, for the levels generated the maximum efficiency of the concrete resistance is achieved with the maximum levels of cement and the standard level of fine aggregate.

## 4. CONCLUSIONS

The ranges considered concerning direct tensile strength with compressive strength for concretes made with aggregates from the Mantaro river and Portland cement type I were considered between 201 kg / $cm^2$ and 420 kg / $cm^2$ and are the ranges of the experiment that they allowed to expand the surface of optimal levels, in terms of the volumes of the materials. Besides, the extension of the working ranges can reduce the consumption of materials, achieving the same resistance that was initially reached.

The Response Surface Methodology is an extremely versatile technique that allows the use of different experimental designs and statistical tools to solve system optimization problems and can be applied to the optimization of a single response or the simultaneous optimization of several responses.

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