Comparison of lightening costs for reinforced concrete gantry

G C Prada-Botía, J P Rojas-Suárez, and M S Orjuela-Abril

1 Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia

E-mail: gaudycarolinapb@ufps.edu.co

Abstract. The selection of suitable materials for a construction defines the costs and characteristics that can contribute to the building, being of vital importance to make a correct choice. Lightening is an element to reduce costs and optimize resources, adding a better index of resistance against earthquakes, being of vital importance the good choice of this: concrete, clay or EPS. In this investigation a comparison of costs and incidence of the three types of lighteners that are used in the construction of three levels houses with reinforced concrete portico based on the requirements of NSR-10 was made by means of statistical samples/data, graphs and tables of data analysis, on the quotations and information collected from different studies on lightening costs in structures.

1. Introduction

The structural gantry system is composed of a spatial gantry, resistant to moment, without diagonals, that resists all vertical loads and horizontal forces [1] it is an excellent system to resist vertical loads for a long time without failing, but it is not considered an ideal system to resist the lateral forces that are generated in high impact earthquakes, because they do not have great resistance and rigidity [2]. Seismic-resistant design has as its main objective the protection of life, improving the seismic behavior of buildings to reduce collapse [3] and due to the fact that in conditions of dense construction of modern cities and the increase in the price of land for construction, many designers and clients bet on the increase in the number of floors of buildings [4], but at the same time vulnerability to earthquakes is increased; being the cause of great financial losses and interruptions in public services for the whole community for long periods of time [5].

Over the centuries, it has been a problem for researchers and engineers to develop different seismic construction designs and technologies to mitigate the effects of earthquakes on buildings, bridges and potentially vulnerable content [6], although in some countries they have created the design rules provided by modern codes (capacity design, force hierarchy) [7].

The main objective of lightening buildings is to optimize resources and reduce the economic cost of construction under predicted functional, aesthetic and safety conditions, adding better anti-seismic behavior [8], being lighter, smaller, easier to handle and transport [9].

The development of the research is focused on a statistical study on the comparison of costs for a type of housing, of three levels, with reinforced concrete portico using different types of lightening according to NSR-10 guidelines [8] in the city of San José de Cúcuta, Colombia, based on the fact that the statistic is the analysis of data that is frequented in several areas, generally used in two areas:

(i) Briefly describe the terms of form, central trend and dispersion of its simple frequency distribution, and

(ii) Make decisions about the properties of the statistical population from sample statistics [10]; with the purpose of being a useful and practical guide that can guide the builder at the time
of building, in turn, taking into account the levels of energy dissipation present in each region.

2. Methodology
The research was applied to buildings constructed with reinforced lightweight plate that applied any of the 3 models (concrete, clay and EPS) in an address located in the city of San José de Cúcuta, Colombia, based on information (grade work) and NSR-10 [8] standards based on earthquake-resistant construction. By means of a statistical study in the collection of data on the quotations of materials it was determined by means of graphs and tables of information, on the quantities of work and costs for the construction [11], in order to compare in percentage form the costs of a housing depending on the lightening that is implemented.

3. Result and discussion

3.1. Analysis of structural cost overrun by type of lightening
Table 1 illustrates the total values and per square meter of the structural model, according to the three types of lightening used; presenting the percentage variations of the costs, demonstrating in this way that the value of a structure with lightweight material in concrete, increases a 7% with respect to the model that uses a lightening in EPS and 3% in relation to the lightening of clay, likewise the structure lightened with block in clay presents an additional cost of 4% with respect to EPS. In addition, EPS can be easily incorporated with different contents in the concrete to produce lightweight concrete with a wide range of density, but has low overall strength [11].

| Lightening | Constructed area | Total value(USD) | EPS cost overrun | Clay cost overrun |
|------------|------------------|-----------------|-----------------|-----------------|
| Concrete   | 313.17           | 38394.70        | 7%              | 3%              |
| Clay       | 313.17           | 37186.88        | 4%              | 0%              |
| EPS        | 313.17           | 35774.52        | 0%              | Does not apply  |

Figure 1 shows the decline in the cost of the structure according to the type of lightening used. It is notorious that the structure lightened with EPS is the most economical among the three types of lightening, obtaining a difference of $2621.33 with the lightened concrete model and $1412.98 with respect to the lightened clay model, while there is a difference between the lightened concrete model and the lightened clay model of $1208.35. Although the price of lightweight concrete is the most expensive, it is a valuable building material due to its good thermal insulation and strength properties [12].

Figure 1. Cost comparison of models by type of lightening.
Table 2, Table 3 and Table 4 show the percentages of incidence of the three structural elements on the total value of the structure, highlighting the cost of the columns due to the dimensions generated in each of the models, taking for each of these, values between 32.53% and 35.83%, but on the contrary the foundation beams showed lower percentages with respect to the total structure, with values between 5.09% and 5.50%; even so, the percentage of costs of the mezzanine and roof plates is perceived, affecting between 15.93% and 18.75% of the total structures without showing greater variation.

Table 2 shows the incidence of the clay block, Table 3 the incidence of the concrete block and Table 4 the incidence of the EPS.

### Table 2. Incidence of the cost per element of the structure. Clay block.

| Item                          | Value per item (USD) | Incidence |
|-------------------------------|----------------------|-----------|
| Footing                       | 3173.73              | 8.53%     |
| Foundation Beams              | 1945.76              | 5.23%     |
| Columns                       | 13323.44             | 35.81%    |
| Mezzanine floor plate h:2.90mt | 6085.60              | 16.36%    |
| Mezzanine floor plate h:5.80mt | 6300.40              | 16.93%    |
| Cover plate                   | 6375.77              | 17.14%    |
| **Total**                     | **37204.70**         |           |

### Table 3. Incidence of the cost per element of the structure. Concrete block.

| Item                          | Value per item (USD) | Incidence |
|-------------------------------|----------------------|-----------|
| Footing                       | 3631.65              | 9.45%     |
| Foundation Beams              | 1955.73              | 5.09%     |
| Columns                       | 13763.69             | 35.83%    |
| Mezzanine floor plate h:2.90mt | 6118.97              | 15.93%    |
| Mezzanine floor plate h:5.80mt | 6469.67              | 16.84%    |
| Cover plate                   | 6471.31              | 16.85%    |
| **Total**                     | **38411.02**         |           |

### Table 4. Incidence of the cost per element of the structure. EPS.

| Item                          | Value per item (USD) | Incidence |
|-------------------------------|----------------------|-----------|
| Footing                       | 2341.01              | 6.54%     |
| Foundation Beams              | 1970.15              | 5.50%     |
| Columns                       | 11643.91             | 32.53%    |
| Mezzanine floor plate h:2.90mt | 6497.50              | 18.15%    |
| Mezzanine floor plate h:5.80mt | 6709.66              | 18.75%    |
| Cover plate                   | 6627.50              | 18.52%    |
| **Total**                     | **35789.73**         |           |

For the mezzanine, deck and foundation beams the variation between them is minimal, while in the footing the changes are more noticeable presenting a maximum difference between the concrete model and EPS of $1290.93. The most significant change is manifested in the columns, being $2120.26 between the concrete structure and EPS, $1679.04 for the clay model and $441.22 for the concrete and clay design, illustrated in Figure 2.

For practical effects, a constant increase in the cost of the finishes of a typical building for a house was contemplated, for which, for the investigation we worked with $400.000 / m², with the objective of
obtaining the economic incidence in percentage values of the structure with respect to the total cost of the building.

![Figure 2. Cost of the element according to type of lightening.](image)

Table 5 and Figure 3 above shows the incidence that each model has in a comparative way with respect to the total cost of the building including the increase per square meter of finishes, it is evident that the concrete model represents an extra cost with respect to the clay model of 1.6%, likewise the structure of the clay model is above the cost of EPS by 1.9%. Finally, the greatest difference is shown in the comparison between the concrete model and the EPS model, presenting a percentage of 3.4% with respect to the total cost of the work.

![Figure 3. Cost comparison.](image)

| Item                      | Clay       | Concrete  | EPS        |
|---------------------------|------------|-----------|------------|
| Built Area                | 313.17     | 313.17    | 313.17     |
| Value per m² of finishes (USD) | 0.12      | 0.12      | 0.12      |
| Template structural total value (USD) | 37214.25 | 38419.81  | 35797.93  |
| Comparisons               | Concrete-clay | Concrete-EPS | Clay-EPS    |
| Value of comparisons (USD) | 1208.60   | 2621.89   | 1413.28    |
| Total building value (USD) | 75533.20  | 76741.80  | 74121.12   |
| Incidence                 | 1.6%       | 3.4%      | 1.9%       |
| Trend                     | 1.6%       | 3.4%      | 1.9%       |
4. Conclusions
In this way, it is very frequent to find construction companies that base their choice of lighteners on the cost and not on the impact they have on a structure, ignoring the effects generated by the loads on the magnitudes of the seismic forces that, in turn, have a percussion on the dimensioning of the elements that make up the structure model.

The modeling of the structure was designed for a sector with special energy dissipation degree (DES), resulting in a 22% increase in the value per square meter of the lightweight material of EPS over the clay material, while a 4% surcharge was obtained in the lightweight model with clay compared to the lightweight model of EPS being this of $1413.88; with respect to the lightweight material of concrete has an surcharge of 6.5% of the value per square meter of the material compared to EPS.

For a structure of three levels aporticada with reinforced concrete, plates lightened and located in an zone with degree of dissipation of special energy, it is possible to be chosen for a lighter material more economic than the clay or the concrete, being the EPS the ideal one when showing benefits of $2623.17 in comparison to the lighter materials previously mentioned, without diminishing positive contributions to the structure.

References
[1] Ministerio del Medio Ambiente Vivienda y Desarrollo Territorial 1997 Reglamento Colombiano de construcción sismo resistente, NSR-10 1997 (Colombia: Ministerio del Medio Ambiente Vivienda y Desarrollo Territorial)
[2] Barros L and Peñafiel M 2015 Análisis comparativo económico - estructural entre un sistema aporticado, un sistema aporticado con muros estructurales y un sistema de paredes portantes, en un edificio de 10 pisos (Ecuador: Escuela politécnica nacional)
[3] Ramírez P C and Fetta A J R 2018 Análisis comparativo del Comportamiento Sísmico Dinámico del diseño normativo sismo-resistente de un sistema dual frente al modelo con aisladores elastoméricos de alto amortiguamiento (HDR) de un sistema aporticado, del Edificio de Oficinas Schell de seis (Perú: Universidad Peruana de Ciencias Aplicadas)
[4] Zenkov E V and Sobolev V I 2018 Numerical modeling of the dynamics of multi- storey buildings with elastoplastic seismic insulators Journal of Physics: Conference Series 1050 012102
[5] Usta P, Morova N, Evec A and Ergün S 2018 Assessment of seismic damage on the exist buildings using fuzzy logic IOP Conference Series: Materials Science Engineering 300 012062
[6] Nath S, Deb Nath N and Choudhury S 2018 Methods for improving the seismic performance of structures: A review IOP Conference Series: Materials Science and Engineering 377 012141
[7] Ruggieri S, Porco F and Uva G 2018 A numerical procedure for modeling the floor deformability in seismic analysis of existing RC buildings Journal of Building Engineering 19 273–284
[8] Asociación Nacional de Poliestireno Expandido (ANAPE) 1996 Manual de Aligeramiento de Estructuras (España: Asociación Nacional de Poliestireno Expandido)
[9] Punlert S, Laoratanakul P, Kongdee R and Suntako R 2017 Effect of lightweight aggregates prepared from fly ash on lightweight concrete performances Journal of Physics: Conference Series 901 012086
[10] Sulistyani N 2019 Error analysis in solving inferential statistics problems for psychology students Journal of Physics: Conference Series 1180 012006
[11] Kan A and Demirboğa R 2009 A novel material for lightweight concrete production Cement & Concrete Composites 31 489–495
[12] Abramski M 2017 Improving thermal insulation properties for prefabricated wall components made of lightweight aggregate concrete with open structure IOP Conference Series: Material Sciences Engineering 245 022034