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DETERMINATION OF THE MODULUS OF ELASTICITY AND POISSON'S RATIO OF CEMENT-SAND MORTAR FOR THE CITY OF OAXACA AND THE SURROUNDING AREA

DETERMINATION OF THE MODULE OF ELASTICITY AND POISSON'S RATIO OF THE CEMENT-SAND MORTAR FOR THE CITY OF OAXACA AND CONURBED AREA

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Abstract *-- The mechanical strength of ferrocement, W-panel and convitec panel structures depends mainly on the characteristics of the mortar used (cement-sand). Therefore, it is necessary to determine the design parameters such as the modulus of elasticity and Poisson's modulus, in order to know the real elastic range in which they work. For this purpose, 15 x 30 cm mortar cylinders were made with cement/sand proportions of 1:2, 1:2.5 and 1:3, following the NMX-C-128- ONNCCE-2013 Standard. To measure the longitudinal and transverse deformations of cylinders, the ring device was used with dial gauges and in other cases electrical sensors, to have a reference of the measurements. The results obtained are applicable for the design of ferrocement structures using mortars made with sand from banks in the City of Oaxaca and gray pozzolanic cement Type CPP 30 R.*

Keywords: Unit deformations, elasticity, ferrocement, convitec panel, W panel and Design parameters.

Abstract *-- The mechanical resistance of ferrocement structures, panel w and panel convitec, depends mainly on the characteristics of the mortar ratio (cement-sand). Therefore, it necessary to determine the design parameters such as the modulus of elasticity and the Poisson's modulus, to know the real working parameters. Therefor, 15 x 30 cm cylinders were made with cement/sand (sand from different deposits) ratios of 1:2, 1:2.5 and 1:3, following the standard according the NMX-C-128- ONNCCE-2013. To measure the longitudinal and transverse deformation of the cylinders, the ring device used to meter cover and electrical sensors, for a reference measurement. The results obtained are applicable to the design of ferrocement structure that use mortars made with sand from deposits in the city of Oaxaca and gray pozzolanic cement type CPP 30 R.*

Key words - Design parameters, elasticity, ferrocement, panel convitec, panel W and unitary deformations.

INTRODUCTION

Mortar is one of the most widely used materials in the construction industry, mainly in the section of walls, since it is used in the joining of the pieces and in the flattening of the walls to give them the finish, although recently the use of structural mortar based on cement and sand has increased.

The modulus of elasticity of the mortar is the result of the different combinations of materials used (Rosell Amigó, J. R 2011). The mechanical properties of these generally depend on the type of cement, its water/cement ratio, the type, quality and origin of the aggregate used (de Guzmán, D. S. 2001). Although the modulus of elasticity is a determining factor in structural calculations, it is not the only one that should be taken into account, since it is directly related to the Poisson's modulus, which plays a determining role in the performance of cement-based materials (Quimbay Herrera, R. 2012). Therefore, it is important to consider the relationship between them, since they will affect the behavior of more complex structures such as ferrocement, W-panel or covintec panel among others (Centeno P. E. M., et al 2015, Rivas, H. W. 2014).

Variations in the modulus of elasticity and Pooisson's ratio imply variations in the deformation capacities in the elastic range of the material, as in the case of the use of mortar for ferrocement, W-panel or convitec applications. In the design of structures, it is important to estimate the distortions that they may suffer and that they do not exceed what is indicated in the building codes (Santibáñez et al. 2004). Currently, only the values proposed in the Complementary Technical Norms for the Design and Construction of Concrete Structures of the Gaceta

Oficial del Distrito Federal (GOBIERNO, D. D. F. 2004), but no parameters are specified for mortar. However, this can be solved by studying the mechanical characteristics of mortars (Sánchez, M. A et al 2015).

Ferrocement is a material widely used in construction due to its easy application, low cost and adaptability (Rosado, O. F. 2017). In the state of Oaxaca (Mecott Gómez, S. 2007), several studies and experiments have been carried out on this material, as can be seen in Figures 1, 2, 3 and 4. These buildings have shown excellent results with the passage of time, natural inclemencies and earthquakes, so it is important to know the mechanical characteristics that allow it to remain standing (Maldonado García, M. A. 2012, Hernández Toledo, U. I. 2010).

The purpose of this research is to determine the modulus of elasticity and the elasticity ratio of Poisson of cement-sand mortars made with three different proportions and from five banks of materials. The results will serve as parameters in the design of structural mortar for ferrocement, W-panel or convitec structures.

MATERIALS AND METHOD DEVELOPMENT

In the preparation of the mortar samples, fine aggregate from five banks of materials from the Oaxaca valley region was used (Table 1), which were sampled according to the NMX C-030-ONNCCE-2004 standard.

Table 1. Water/cement ratio different cement: sand ratios.

Banks	Ratio in volume (cement:sand)		
	1:3	**1:2.5**	**1:2**
Guadalupe I	0.57	0.5	0.44
Guadalupe II	0.56	0.49	0.42
San Lorenzo	0.56	0.49	0.42
Magdalena Apasco	0.56	0.49	0.42
Xochimilco	0.56	0.49	0.42

Each sample was reduced until a sufficient portion was obtained to perform granulometry, density and absorption characterization tests. For each material, mortar cylinders were made with mixtures in proportions of cement:sand 1:2, 1:2.5 and 1:3.

Water-cement ratios by weight were obtained for each bank of material as shown in Table 1. Portland cement type CPP 30R (sulfate resistant) was used as cementitious material.

Cylindrical specimens of 15 cm in diameter by 30 cm high were made following the specifications of the NMX-C-ONNCCE-083- 2014 standard for hydraulic concrete specimens, since there is no standard in Mexico for the production of cylindrical mortar specimens. In addition to the cylinders, mortar cubes of 5 cm per side were elaborated according to NMX C-061-ONNCCE-2016.

For each cement-sand ratio, 5 cylinders of mortar were made, of which 2 were used for compressive strength and 3 for modulus of elasticity tests. In addition, 3 cubes were prepared for each ratio to determine compressive strength. In total, 15 cylinders and 9 were obtained for each bank of materials. The tests of the cylinders and cubes were carried out 21 days after the production of the cylinders and cubes.

The design of the mix was based on Dr. Abrams' Curves and Monograms Method. It is worth mentioning that originally this method did not contemplate the design of mortar mixes, so it was necessary to adapt it in order to obtain a mortar mix dosage with the required strength.

The modifications made were as follows:

- The gravel-sand ratio by weight (G/S) was assigned a constant value of 0.
- Working conditions remained rigid (R).
- Water consumption was adapted to the workability of the mix.
- The volume ratio was sought to give values for the volumetric proportions
  1:2, 1:2.5, 1:3 or 1:4, for which the value to be varied was that of the load fatigue.

METHODOLOGY

The hydraulic cement mortar that was designed is intended to be of the structural type applied for the city of Oaxaca and its suburban area, so it was important to determine the parameters of modulus of elasticity and Poisson's ratio following the NMX-C-128- ONNCCE-2013 standard for hydraulic concrete.

DETERMINATION FROM MODULE DE ELASTICITY Y THE DE RELATIONSHIP POISSON

DEFINITIONS

The Modulus of Elasticity E represents the slope of the line between the stress corresponding to a unit strain of 0.00005 and the stress equivalent to 40% of f'c (Figure 1), where f'c is the compressive strength.

axial at 28 days of age of cylinders of 15 cm in diameter by 30 cm in height.

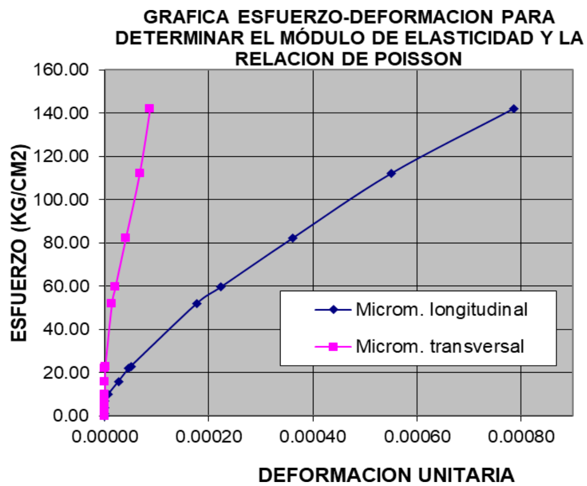

Figure 1. Stress - Strain Graph

Elasticity, as defined by Magdaleno (1982), is the property that allows a body to deform under the action of external forces, in such a way that a relationship is established between forces and displacements and when the loads cease to act, the body must recover its initial shape.

It is also defined as the ratio between the applied stress and the instantaneous unit strain within a considered proportional limit, extending to the limit as the allowable stress boundary, before the material undergoes permanent deformation or the point where the line departs from straight and starts to be curved.

The modulus of elasticity under tension or compression stresses will always be governed by the slope of the stress-strain curve of concrete under uniaxial loading. In the case of concrete, as shown in Figure 5, this curve does not present a linear behavior; therefore, three methods are used to determine the modulus of elasticity.

- **Tangent modulus**: It is determined by slope of a tangent line drawn at any point on the stress-strain curve.

- **Secant modulus:** This is given by the slope of a straight line drawn from the origin to a point corresponding to 40% of the fault load.

- **String module:** Se obtains by la slope of a straight line drawn from a point representing a longitudinal unit strain of 19.7 x 10-6 ucm/cm, to the point at 40% of ultimate load.

Regarding the modulus of elasticity of mortar, Wainshtok (1992) determined through research that mortar has a modulus of elasticity generally lower than that of concrete of the same strength, and that in the absence of other specially elaborated indications, the recommendation of the Russian standard for ferrocement can be taken as a reference, which allows estimating the modulus of deformation of mortar equal to 0.80 of the modulus determined for concrete of the same strength.

POISSON'S MODULUS OR RATIO

Fitzgerald (1990) expresses that, Simon Daniel Poisson, in 1828, presented in the Academy of Paris the concept of:

$$\mu = -\frac{\cdot}{\varepsilon_{Longitudinal}} \qquad \text{Eq. (1)}$$

which can be defined as the ratio in which the specimen deforms transversely to what it deforms longitudinally, and is expressed by the term μ. , when When an element is subjected to tensile or compressive stresses, in addition to the deformation in the direction of load application (longitudinal deformation), transverse or lateral deformations are generated, which, when relating the unit lateral deformation to the unit longitudinal deformation, a known value is obtained.

as Poisson's ratio or coefficient μ

As stated in Standard NMX-C-128- ONNCCE-2013, Poisson's ratio is calculated from the transverse deformations measured at half the height of the specimen, according to the following expression:

$$= \frac{\varepsilon_{tB} - \varepsilon_{tA}}{\varepsilon_{B} - 0.000050} \qquad \text{Eq. (2)}$$

Where:

ε_{tB} = transverse deformation produced by a stress equivalent to 40% of the rupture stress.

ε_{tA} = transverse deformation that manifests itself with the stress that produces a longitudinal deformation of 50 millionths (0.000050).

ε_{B}= longitudinal unit strain for the stress equivalent to 40% of the rupture stress.

The equipment used for the modulus of elasticity measurements was a Compressometer-Extensometer for concrete cylinders, which measures both the axial and diametral deformation of the cylinders. It consists of two parallel metallic rings 15 cm apart, both placed in the middle part of the cylinder height; the lower ring is fixed to the sample by means of metallic punches that penetrate the surface layer of the mortar and the upper one only at two diametrically opposite points with freedom of rotation. These rings are connected with a pivot and the deformations on the opposite side are recorded in the following way
a dial micrometer with a dial micrometer approach of 0.002 mm.

There is a third ring formed by two segments and located between the other two rings mentioned, which is fastened with two punches located diametrically opposite and where the segments are joined, a micrometer is housed (Figure 2).

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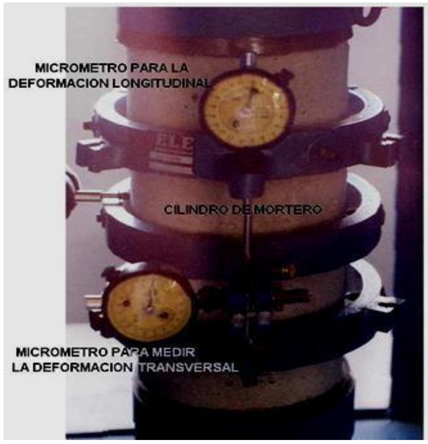


Figure 2. Arrangement of equipment for measuring modulus of elasticity in cylinders.

The recommended test procedure contemplates having 5 samples (cylinders), two to be tested in compression until rupture, which is called f'c of the mortar, and the other three cylinders are tested until they moderately exceed 40% of that maximum load to calculate the Modulus of Elasticity and Poisson's Modulus of Elasticity.

Once the measuring device was attached to the cylinder, the micrometers were adjusted to zero reading and two or three cycles of preloading and unloading were applied, between 10 to 15% of the maximum load, a procedure that is useful to verify and adjust the operation of the equipment. For each load application, the corresponding deformations were recorded and subsequently the respective Moduli were calculated.

DISCUSSION AND ANALYSIS OF AGGREGATE RESULTS

The granulometry of the materials sampled in each bank is shown in Figure 3, showing that some of them do not comply with the NMX-C-077-ONNCCE-2019 Standard, since they exceed the upper limit, mainly the San Lorenzo bank, and the Xochimilco and Magdalena banks in meshes larger than number 16.

After performing the granulometric analysis of the sands, we observed that all of them have a coarse sand granulometry based on their fineness modulus (Table 2), even when sieving the sands through mesh number four, we observed the same tendency, being suitable for their use.

in the production of mortars and hydraulic concretes.

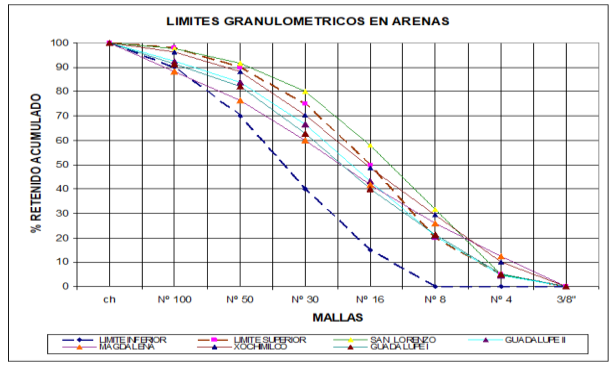


Figure 3. Granulometry of sands of the sampled banks.

Table 2. Physical properties of fine aggregate.

Banks	Modulus of fineness	Density (g/cm3)	Absorption (%)	Loose Dry Vol. Weight (kg/m3)
Guadalupe I	3.03	2.59	2.09	1531
Guadalupe II	3.05	2.57	2.2	1519
San Lorenzo	3.64	2.64	1.4	1535
Magdalena Apasco	3.43	2.69	1.4	1585
Xochimilco	3.04	2.54	2.4	1523

MODULUS OF ELASTICITY AND POISSON'S RATIO

To determine the relationship of the compressive strength and modulus of elasticity data set, the results obtained from the tests for both cylinders and cubes were plotted and fitted to a linear function, obtaining coefficients of determination of 0.8859 for the cubes and 0.62 for the cylinders (Figure 4).

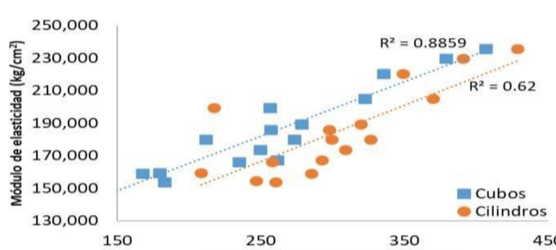
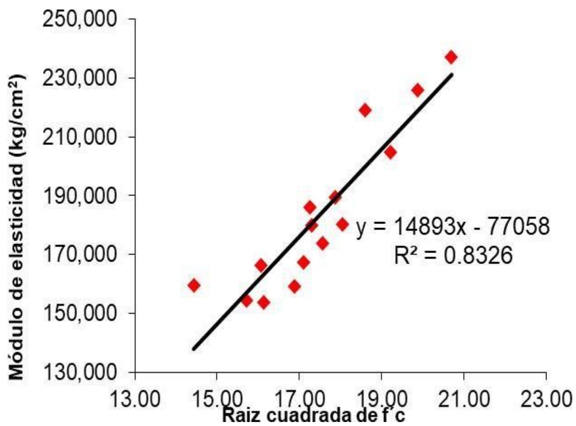


Figure 4. Relationship between modulus of elasticity and compressive strength

The complementary technical standards for the design and construction of concrete structures in Mexico City (GOBIERNO, D. D. F. 2004) establishes an equation that allows estimating the modulus of elasticity of concrete based on the square root of the f'c, for which we proceeded to plot the values of $\sqrt{f'c}$ and the modulus of Elasticity (Figure 5). From this, general equation (equation 1) is defined for all banks to determine the Modulus of Elasticity of mortar ($\boldsymbol{E_m}$) as a function of the square root of the compressive strength of mortar cylinders.
cement-sand (**f'c**).

$$\boldsymbol{E_m} = -0.0007\sqrt{\boldsymbol{f'c}} + 0.1468 \qquad \text{Eq. (3)}$$



Relationship between square root values of f'c and modulus of elasticity of hydraulic mortar cylinders.

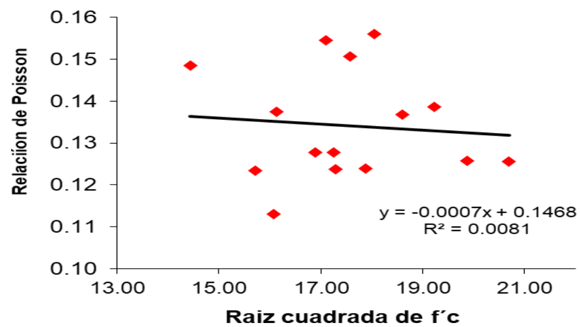
Similarly, the values of the square root of the f'c and Poisson's ratio obtained in the

The coefficient of linear determination is very low, so it is not possible to have with certainty an expression that relates both parameters:

$$\boldsymbol{\mu_m} = -0.0007\sqrt{\boldsymbol{f'c}} + 0.1468 \qquad \text{Eq. (4)}$$

Once the equations of modulus of elasticity and Poisson's ratio have been obtained in general form, it is observed that the coefficients of determination of the linear fits are low, which is the reason for the low coefficients of determination of the linear fits.

which led to calculate equations of the modulus of elasticity for each bank of materials, because each bank of materials presents different granulometric behavior (particle size and shape). The linear fits of each bank of materials are presented in Figure 7, in which better trends are observed with
based on their coefficient of determination R2,
except for the Guadalupe 2 bank whose coefficient of determination is lower than the average of the adjustment of all banks.



Relationship between square root values of f'c and Poisson's ratio of hydraulic mortar cylinders.

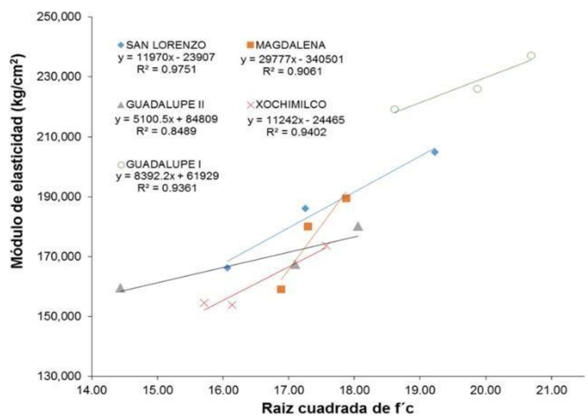


Figure 7. Linear fits of each bank for the relationship between the square root of f'c and modulus of elasticity of mortar cylinders.

As can be seen in Figure 8, the mortars made with the aggregate from the Guadalupe I bench have higher modulus of elasticity than the rest, this could be due to the fact that it has a better distribution of its particles (Figure 8) and generates denser mortars, unlike what is observed for the other benches.

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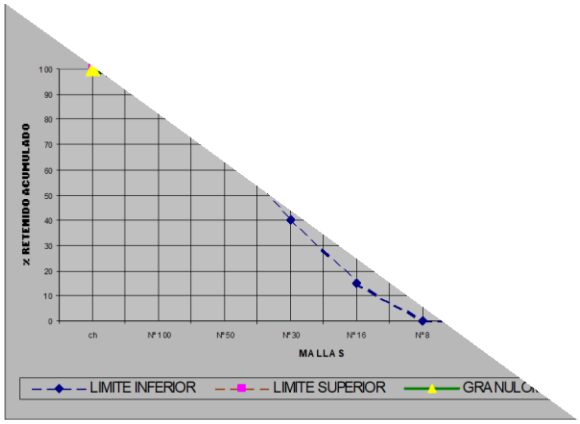

Figure 8. Granulometric distribution of fine aggregate from Guadalupe I bench.

The adjustment equations for the different banks are presented in Table 3, from which it can be determined that the slopes of the adjustments are more similar between the Guadalupe I, San Lorenzo and Xochimilco banks. The trends change with the Guadalupe II bench with a lower slope than the average and the Xochimilco bench with a higher slope than the average.

Table 3. Equations of the linear adjustments.

Ba	
Guadalupe I	
Guadalupe II	5,10
San Lorenzo	11,$f'c$ √
Magdalena Apasco	29,777 $f\sqrt{c}-340$
Xochimilco	11,242 $f\sqrt{c}-24465$

Although the coefficients of determination of the fit are improved by analyzing the trends individually, a larger range should be considered in providing a clearer trend in the relationship between the square root of the compressive strength of mortars and their modulus of elasticity.

The results obtained can be used to estimate the modulus of elasticity of mortars with the proposed proportions and to have greater certainty in the design of structural elements made with this material for the city of Oaxaca and its suburban area, depending on the bank from which the fine aggregate is obtained.

CONCLUSIONS

Dr. Abrams' curves and monograms design method can be used for the design of mortar mixes, with the modifications mentioned in the materials and method section.

Variations in the physical parameters of fine aggregate between material banks modify the trends in obtaining a general fitting equation relating the square root of the compressive strength of concrete to its modulus of elasticity.

A better particle size distribution of the fine aggregate improves the mechanical behavior of the mortar.

The results of this study are important for the technical environment, since they can be applied to the design of ferrocement, W-panel and convitec panel structures.

Further research is required to determine standards that are applicable in the design of structures that use mortar in a structural manner.

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IPSUMTEC
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Conceptualization, Methodology, Validation, Formal Formal Analysis, Research, Writing Preparation of the original draft , Writing - Proofreading and editing	Dr. Ramirez Ramirez Ortiz Arturo Emanuel (same)
Conceptualization, Methodology, Validation, Formal Formal Analysis, Research, Writing Preparation of the original draft , Writing - Proofreading and editing	Dr. Cosmes López Mario Fernando (same)
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