

ANTONIO RAMOS'S MANUSCRIPT.

Analysis of a scientific text with an empiric base.

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Preamble.

From the middle of the XVI century we find authors worried to find rules that allow get with guarantees elements of structures. The concept is not new, always empiric rules had been used. However, this gets importance when the proposed confirmation tools use mechanical concepts, then the empiric knowledge shares place with the scientist.

Inside the field that personally occupies us, the construction of vaults, the problem to solve was clear always. It was necessary to know as much as it pushes an arched construction on their supports, to be able to check if these dimensions were correctly.

Authors like La Hire, Belidor and Gautier expose their own theories and confirmation methods, more than enough well-known and even commented in the national editions previous of the association that it promotes this congress.

By the middle of the XVIII century, the figure of a Spanish architect, Antonio Ramos, that exposes its own method starting from the previous theories, compiled in a manuscript carried out by responsibility of the *Real Academia de Bellas Artes de San Fernando* appears.

To write about the manuscript as document is not the objective of this communication, so we will center in the interest and validity of the method of confirmation of supports that it proposes.

Content of the manuscript.

The document that has arrived us is divided in seven notebooks:

Table 1. Content of the notebooks of the Antonio Ramos's manuscript

Notebook n°	Content
1	<i>1ª Cuánta potencia o impulso se necesita para volcar un pie derecho, pilar o muro en cualquier punto de él en que se haga el empuje. 2ª Cuánto gravita cada volsor o dovela de un arco contra el pie derecho o pilar que lo sostiene.</i>
2	<i>Parte II De las propiedades del medio arco y su pie derecho.</i>
3	(Por la muerte del autor, quedó sin ordenar)
4	(Operaciones prácticas)
5	<i>En gracia de los que no hayan estudiado esta doctrina de las proporciones parte esencial de la Aritmética que suponemos.</i>
6	<i>En limpio.</i>
7	<i>Primer borrador.</i>
Figuras	Cuaderno de figuras (incompleto)

After reading their reflections, we can reach the conclusion that the author proposes his method being based on two fundamental aspects: the knowledge of the theories and precedent methods and the observation of the reality.

Also, the curious of method is that it is really a confirmation method just as we understand the concept at the present time. It leaves of some dimensions proposed a priori (predimensions) for those that it uses an empiric formulation and later on it uses an analytic method that been worth or it corrects the proposed dimensions (calculation).

To deepen in their positions it is interesting to begin with the notebook nº 5 where is analyzed and they comment the methods of the previous authors:

... del Sieur Gautier y Mr. Belidor que trataron del modo de encontrar los estribos de los arcos como en sus proposiciones se manifiestan y aunque dichos autores no han demostrado completamente lo que proponen, pues Gautier sólo demuestra la fuerza que hace una palanca curvada a buscar su natural, que es estar recta, lo que demuestra por triángulos semejantes, sin hacerse el cargo del peralte de su dovela ni de sus divisiones, ni da elevación alguna al pie derecho, circunstancias muy precisas en todo género de arcos y bóvedas.

Mr. Bélidor está más extenso y da espesor a las dovelas, hace su división y se hace cargo del pie derecho; pero no da razón de sus operaciones por demostración, como se puede ver en sus proposiciones ...

... y aunque los dos expresados autores no perfeccionaron los expresados problemas no puedo dejar de loarlos...

Once centered the problem, translates to Bélidor in the exhibition of the previously exposed method, and the following conclusions where it describes the mechanism of break of an arch settles down (perfectly defined):

*...Según la experiencia nos enseña, el medio arco y su pilar son un pie derecho, y si se mueve es sobre su hipomoclio.
2º Si el medio arco tiene más potencia que resistencia, el pie derecho se siente en las juntas de su clave siguiendo la fracción casi perpendicular.*

3º Y si la escasez del estribo es mucha, se siente en los tercios y se desploma el pie derecho hacia la parte exterior del hueco del arco, moviéndose unido el pie derecho con los volsores que están sobre su imposta hasta la mitad del medio arco o cuadrante.

4° El resto de volsosres hasta la clave se desprenden hacia el centro del arco casi unidos, variando de sentir sus juntas, pues la fuerza de la frasi3n del tercio siempre se queda m3s ancha en la bocilla inferior del arco que la superior, y la fracci3n de la junta hacia arriba sigue casi perpendicular.

Theoretical foundations.

Although in the notebooks 6° and 7° it outlines the same problems again, it is in the notebooks 1° and 2° where the author proposes his analysis method. In the first notebook he/she tries to obtain:

Cu3nta potencia o impulso se necesita para volcar un pie derecho, pilar o muro en cualquier punto de 3l en que se haga el empuje.

To solve the problem, it assimilates the stirrups to a lever, defining it as:

... un cuerpo largo e inflexible que de tal modo descansa y se afianza sobre un punto, que s3lo puede moverse alrededor de 3l como si fuera su centro.

In the figure 1, their propositions can be appreciated, as for the laws of the lever and their peculiar form of trying to the angular levers.

In fact, it tries to the support as levers of 2° order, in those that the resistance is located among the *hipomoclio* (turn point) and the power. In this type of levers, the product of the power or resistance for their respective distances to the *hipomoclio* should be identical so that the lever is in balance.

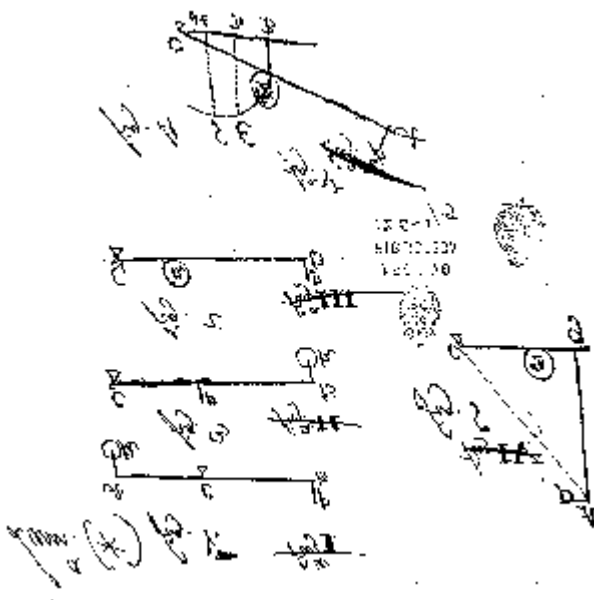


Fig.1. Types of lever according to draws of A. Ramos.

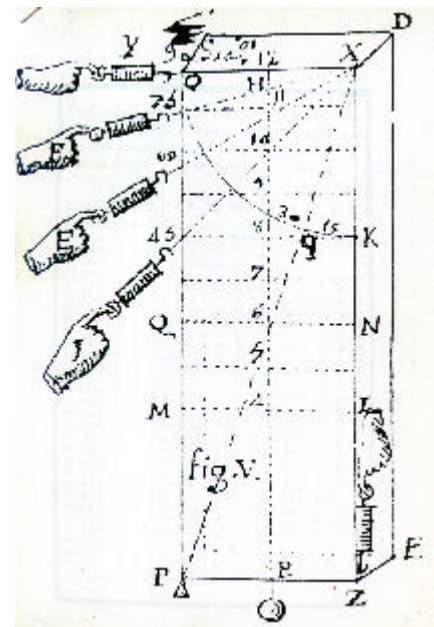


Fig.2. Figure V of sheet IV of A. Ramos's manuscript.

The figure 1 that represents to a sheet without to classify contained in the notebook n° 6, develops different types of levers. Inside this sheet, the figures 2, 4 and 5 contain levers of 2° order.

To solve the fundamental problem it uses the figure V of the sheet IV (fig. 2). Once he obtains the maximum power that is necessary for the balance, when this forms right angle with the horizontal one,

he obtains that fraction of this gets lost when it acts with a certain inclination. To establish this relationship, it proposes the following thing (proposition 4^a, notebook 1^o):

Si un pie derecho es oprimido por una potencia verticalmente, su resistencia será según el ángulo que causa la dirección vertical con la perpendicular de la línea o columna de dirección que pasa por el centro de gravedad.

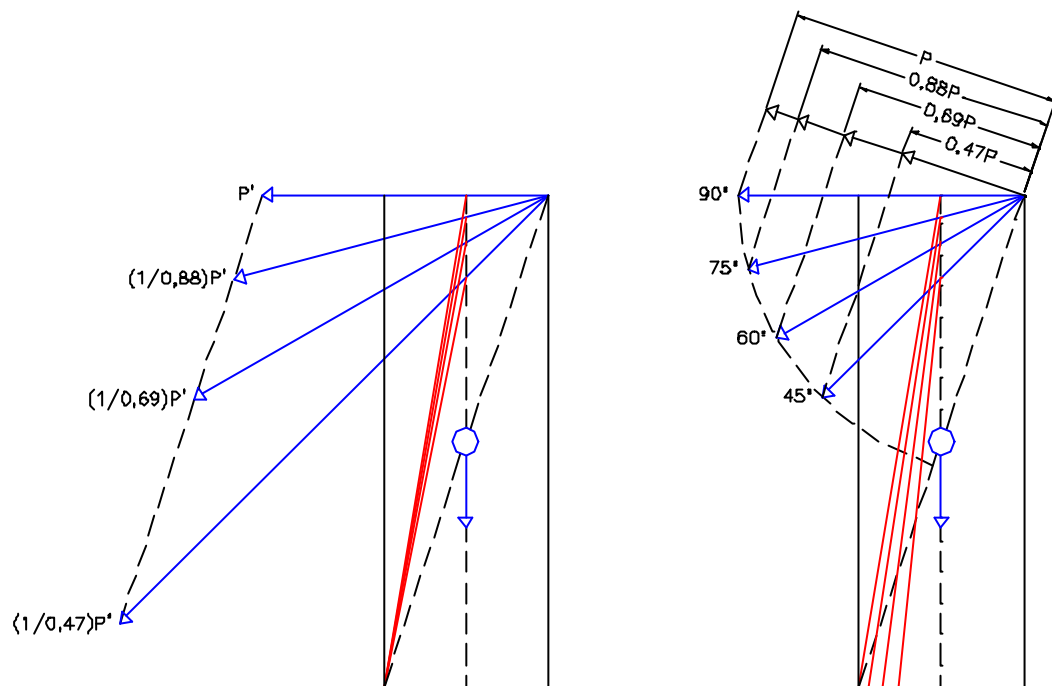


Fig. 3. Pushes and turn according to the angle of the power.

In the figure 3 the problem has been represented. In the left part of the figure it is observed like it is necessary to increase the value of the power (P') so that the balance takes place between power and resistance (the resultant of both actions goes by the *hipomoclio*). In the right part it is obtained as much as he decreases the value of the power in function of the angle that forms with the vertical one.

As A. Ramos settles down this relationship is similar to:

$$P_{\alpha} = P \frac{\alpha}{90^{\circ}}$$

Relationship that becomes an acceptable approach to the correct solution in function of the proportions of the support (axh, wide for high). Evidently it is easy to obtain the correct solution, being this similar to:

$$P_{\alpha} = P \left(\operatorname{sen} \alpha - \frac{a}{h} \operatorname{cos} \alpha \right)$$

With the previous expression we can obtain that when a/h is similar to $\tan(\alpha)$ the power is annulled totally

or what is the same thing its action line goes by the *hipomoclio*.

Aspect that doesn't contemplate the relationship that A. Ramos settles down.

In the figure 4 the comparison has been represented among the relationship settled down by the author of the manuscript and the real solution for different proportions of the support.

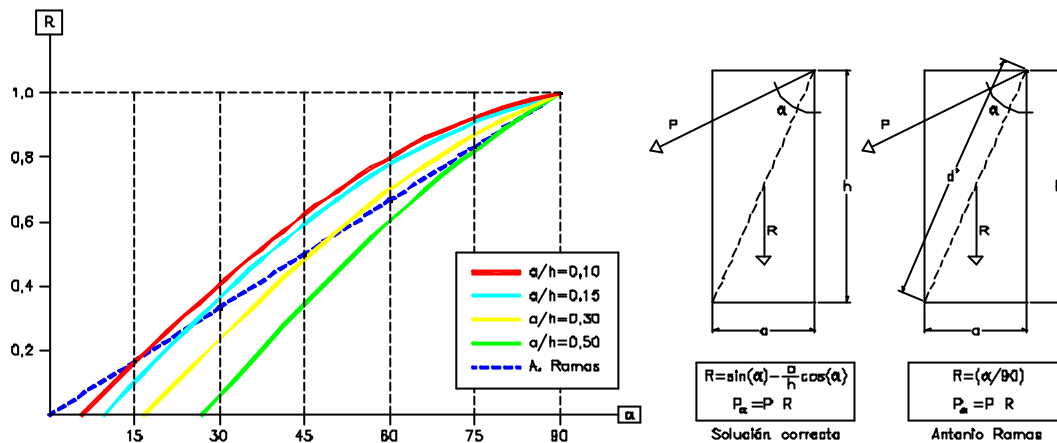


Fig. 4. Relationship between angle and right powers with the same result. Comparison between real solution and A. Ramos propositions.

In the table 2 the values of the powers are exposed that are obtained of the previous comparison, and the error percentage that A. Ramos makes.

Table 2. Comparison between real solution and A. Ramos propositions.

"	a/h=0,1			a/h=0,2			a/h=0,3			a/h=0,4		
	Real	Ramos	%Error	Real	Ramos	%Error	Real	Ramos	%Error	Real	Ramos	%Error
15	3486	3582	273	5560	14120	15393		31033			53480	
30	8885	7164	1936	27686	28240	200	44724	62067	3877	49284	106960	11702
45	13677	10746	2143	47926	42361	1161	92165	93100	101	136138	160440	1785
60	17538	14328	1830	64899	56481	1297	133325	124134	689	213715	213921	9
75	20204	17910	1135	77449	70601	884	165399	155167	618	276727	267401	337
90	21492	21492	0	84722	84722	0	186201	186201	0	320881	320881	0

We observe like it stops proportions between the interval 0,2-0,3 and angles non superiors at 30°, the error that is made (13%) it is perfectly acceptable.

Proposed method.

After this interesting preamble, in the notebook 2°, it is the fundamental aspect of the manuscript that is:

Cuánto gravita cada volsor o dovela de un arco contra el pie derecho o pilar que lo sostiene.

The notebook 2° begins this way:

Antes de entrar en la demostración de los arcos y de como hacen su empuje contra su pie derecho ya sean semicirculares, escarzanos, elípticos, a cordel, o de la forma que sean, y lo mismo en todo género de bóvedas de cañón, es menester prevenir que guardan unas mismas propiedades, esto es que el

...

Luego el medio arco y el pie derecho tendrán las mismas proporciones que se han demostrado en la primera parte hablando de los pies derechos: esto es que la resistencia del pie derecho será según fuese la distancia que hay del hipomoclio G al punto F que es por donde pasa la línea de dirección FD que pasa por el centro de gravedad dividiendo la superficie del pie derecho y arco en dos partes iguales por ser el compuesto un sólo pie derecho $ACZKEMHG$.

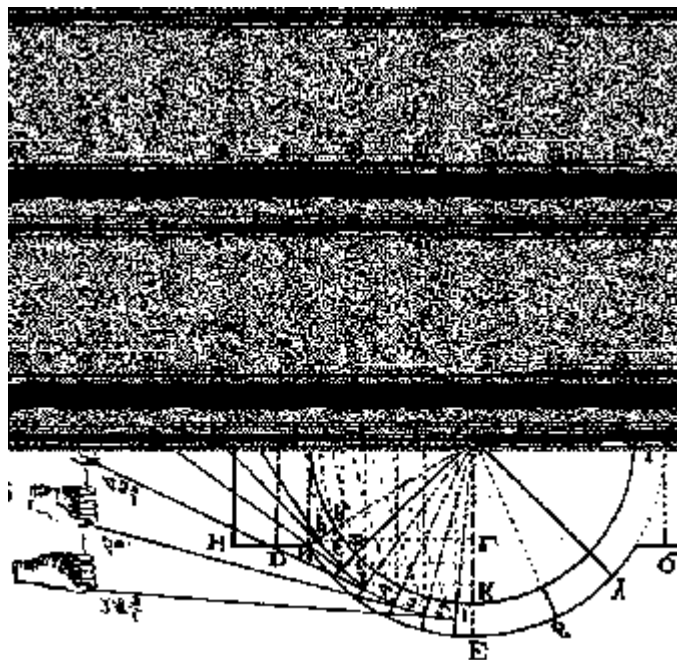


Fig. 5. Sheet VI of the manuscript

The figure 5 that reproduces to the sheet VI of the manuscript it contains the confirmation model that will use in the calculations.

It is in the sheet VII (figure 6) the one that will use to carry out the confirmation of the fundamental proposition of this notebook (proposition I, notebook 2°):

Digo que los volsos no emplean más esfuerzo contra su pie derecho o volsor inmediato, que el ángulo que forma la línea perpendicular que sale de su junta y termina en la columna, o la línea de dirección que pasa por el centro de gravedad del arco y pie derecho, la que se supone perpendicular al horizonte

HX.

The rest of propositions contained in the notebook is devoted to obtain the different surfaces and distances that he needs to carry out the main demonstration that is that the support has enough dimension to resist the push of the arch. Therefore the previous paragraph, contains its fundamental theory, already exposed in the previous chapter:

Cada _ (dovela) plantea su esfuerzo en función del ángulo que forma la perpendicular a su plano de asiento.

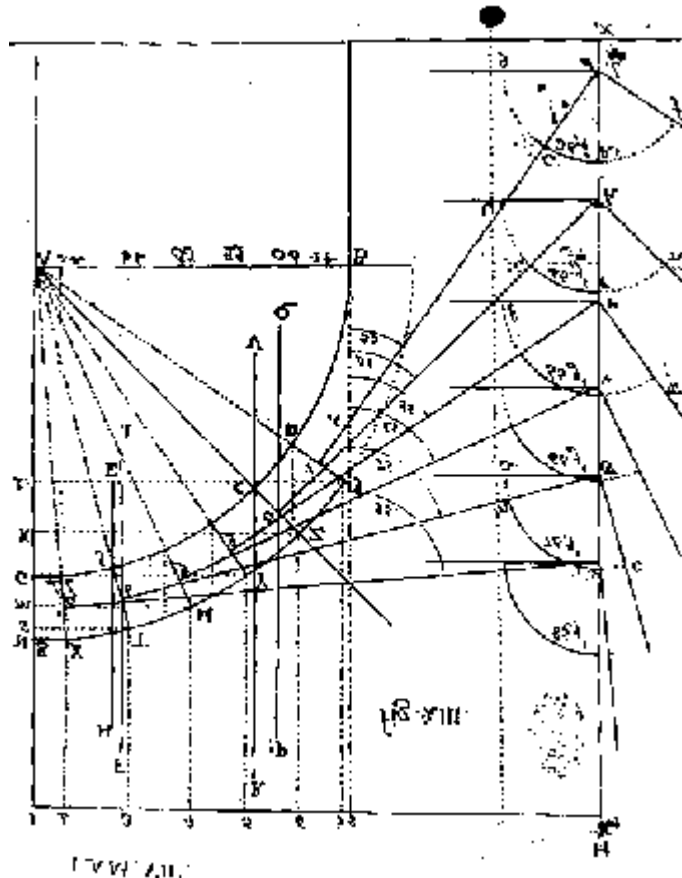


Fig. 6. Sheet VII (fig. XIII) of manuscript.

According to the above-mentioned, if each dovela has a weight (P) and its action line (always) vertical) it forms a certain angle with the meeting with regard to the following one, if it is considered an entire single right foot, the fraction of power that makes action it is obtained according to the angle, just as he/she settled down in the first notebook.

Once obtained this fraction of power for each one of the dovelas, starting from their distance until the hipomoclio, the overturn action is obtained that the arch or vault is carrying out on the right foot (pillar or wall more semiarco).

Use of an empiric formula.

Once defined the confirmation method, from a practical point of view, is necessary to carry out a predimensionated of the element to check. The formula that utiliza A. Ramos are the following one:

$$e = \frac{l}{2} \sqrt{h + l + r + S + P}$$

Where:

e = wide of the looked for support

h = height of the support

l = height of the vault

r = radius of the vault

S = surface of the half-arch

P = power of the half-arch (calculated according to their method).

The formula gets the attention because it mixes magnitudes of different dimensions (lineal and superficial). The most interesting thing is that it introduces adding the power of the semiarco, magnitude that is directly proportional to the push and therefore to the width of the looked for support. From this point of view, the formula can be used for any arch type (reduced, semicircular or pointed).

Evaluation of the method.

As it is observed starting from their positions (forces perpendicular to the joints, each piece of arch contributes a certain fraction of the push, the whole group it constitutes an only support and application of the rules of the lever) the method is an approach to the problem.

To evaluate the approach degree that A. Ramos gets, in the following table their calculations have been re-done, starting from the formulation that proposes:

Table 3. Calculations of A. Ramos

"	P (pies2)	Pot (pies2)	Dist (pies)	Momento (pies3)
85°	4.31	4.07	57.34	233.38
75°	8.63	7.19	55.91	401.99
65°	8.63	6.23	54.16	337.43
55°	8.63	5.27	52.12	274.7
45°	8.63	4.31	49.82	214.74
35°	8.63	3.35	47.3	158.46
Total:				1620.7

The figure 7 includes the dimensions that he uses. In the previous table, (°) it is the angle that forms each joint with the vertical one, (P) it is the weight of each one of the piece of arch, (Pot) it is the power of each one obtained in function of the angle of the joint and (Dist) it is the distance from the center of each joint until the *hipomoclio*. In function of the previous results, a total moment of 1620,70 pies3, is obtained that corresponds to a resistance of 322,22 pies2. As the group denominated support possesses 391,06 pies2 of resistance, the dimation is correct.

Certainly, the part more difficult of accepting of their theories it is the corresponding to the obtaining of the value of the push that although he is not him in an explicit way he obtains it like successive sum starting from the load of the piece of arch and of their inclination of joints. From our current optics we

know that the push is the horizontal component from the stress to which are subjected the different piece of arch that in a case as this in the one that the actions are all vertical ones has an unique value for the whole arch. From this position, using the total moment that A. Ramos obtains, we can obtain the value of the push (H) just as we understand it today in day to see in that field of variability moves. The figure 8 represents the problem. The moment calculated by A. Ramos are equal to $(H \times h)$. Making the previous operation obtains that for $h=53,55$ feet, $H=30,26$ pies².

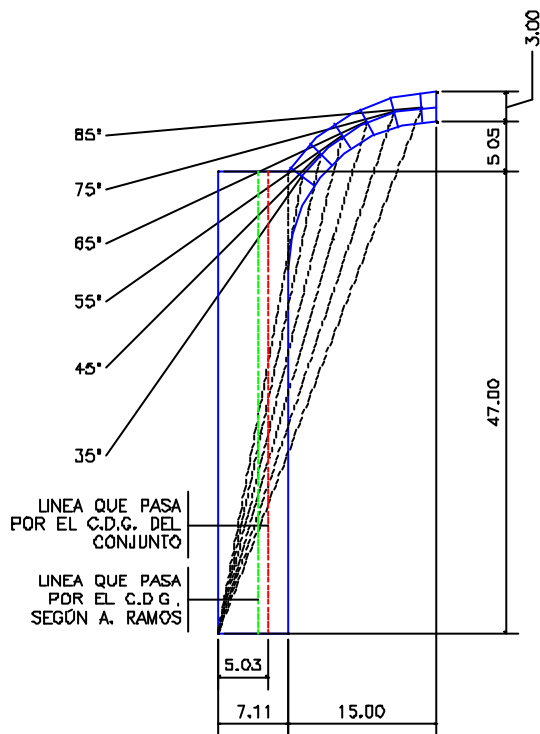


Fig. 7. Model based on the figure XI of the sheet VI of the manuscript

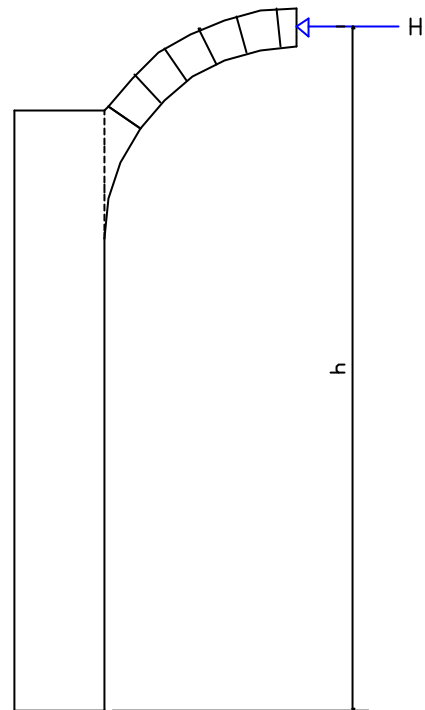


Fig. 8. Real push (H) in an arch or vault.

Therefore the relationship that is obtained among the push H and the vertical load of the half-arch (H/V) it is similar to 0,63 that it is quite acceptable.

As we see, for the type of arch used and for the proportions of the used support ($a/h=0,15$), the method fits sufficiently. However, for another type of arches, mainly reduced, we can sense as their application it won't be so correct since obtaining the push starting from the load fraction in function of

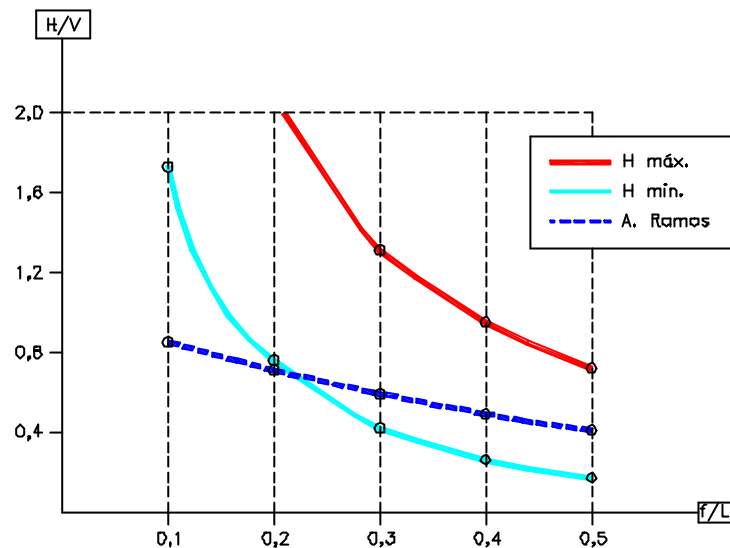


Fig. 9. Relationship between the pushes (H/V) according to A. Ramos and the maximum or minimum real for different relations (f/L ; high/span) of arches

the angle of the joints, difficultly relationships will be obtained (H/V) superiors to the unit that are characteristic in very reduced arches. The figure 9 analyzes the problem.

The results are conclusive. For relationships (f/L) inferior at 0,20 the method is not valid, however for superior proportions up to 0,50 (semicircular arch) the obtained results are very satisfactory.

Conclusions.

This Spanish contribution continues in the line of methods that only check the dimensions of the contention elements and they don't lend, still, attention to determine the stability of the arch in function of its geometry and thickness. Fact that is demonstrated by the use of normal directions to the joints like actions carried out on the support and not how distribution of stress inside the arch or vault.

However, the use of an empiric formula for pre-dimension the structure transforms to the work method into a compact tool for diverse geometries of arches, with a degree of sufficiently high success, just as we has been proven.

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