v. 3, n. 18, 2023

Journal of
Engineering
Research

STRUCTURAL ANALYSIS OF GALLERY NUMBER 4 OF 25 M LENGTH AND THE DETERMINATION OF THE TOTAL LOADS TO BE SUPPORTED ON THE ROOF OF A CONCRETE BUILDING WITHIN AN OPERATING CEMENT PLANT

Luis Orlando Cotaquispe Zevallos
``Pontificia Universidad Católica del Perú``.
Faculty of Sciences and Engineering

Abstract: After reviewing the general plans of the Project regarding the need to transport the cement within the existing Plant to a new 75 m^3 Buffer Silo; In order to increase production, the circuit was designed by Galleries, which serve as supports for the square ducts for transport by blown air, where the existing buildings were also used, but maintaining the safety and efficiency standards for a Plant. of cement already operational. The solution for this new transport of cement through pipelines involves the design of structural galleries that will support the weight of the dead and live load, the weight of the gallery ducts and the accessories for transportation. It is important to point out that the structural supports of the galleries and their construction forms have been evaluated according to the circuit, the most critical route being that referred to Gallery 4, because it rests on the roof of a concrete building, which is why which the present applied research work presents the Design of Gallery 4 and its necessary support supports for anchoring on the roof. The length of Gallery 4 is 25 meters and inside it supports a double square transport duct with 3 inspection grills for personnel.
Keywords: Design, structure, rigidity, anchorage.

INTRODUCTION

After carrying out the general plans of the entire project that includes 5 Galleries for the transport of the cement to the Silo Buffer, the general loads on Gallery 4 are obtained in a particular way (see figure 1); where the loads of the structural support base of the entire Gallery 4 have not yet been defined and the support structures for the 5 proposed supports have not yet been evaluated (see figures 2 and 3).

ANALYSIS OF THE LOADS ON THE GALLERY 4

The total loads have been evaluated considering live loads in that area of the circuit, dead loads of the equipment and the load-bearing structures shown. All this evaluation is presented in Table 1 in detail until the reactions of the supports on the roof are obtained existing, which will be evaluated by professionals in Civil Engineering.

It is important to note that figures 2 and 3 show the sections of Gallery 4; the first section will have 3 supports for a length of 16,679 mm and the second section will have 2 supports for a length of 8,376 mm; which will be on the roof of the existing building.

CALCULATION OF THE SUPPORTS OF THE GALLERY 4

Figure 4 shows Galleries 4 and 5 connected, so an arrangement of supports will be needed, the number of which will be important to define, in order to distribute the loads more safely on the existing roof. It is also important to point out that Gallery 4 is broken in different lengths, which makes it necessary to place a different number of supports, that is to say that for the section of length 16679 mm 3 supports will be placed (A, B, C) and for the section 8376 mm long, 2 supports (D, E) will be placed.

In addition, the distance of the supports of structural frames will be tentatively assumed based on the location of the beams and columns of the existing building according to civil works plans. In addition, with the total loads on gallery 4 (see table 1) there will be a distributed load along each section and a point load on each support due to the weight of the supports and whose design is presented later.

In figure 5; the Free Body Diagram (FBD) is presented for each section and the final values of the internal load (reactions) in the

Gallery 4 with a broken length of approximately 25,055 mm	Base structure weight(kN)	Force V wind (kN)	P_{TOTAL} + seismic effect (kN)
L = 16679mm Width = 3020mm	11.42	2.14	184.64
L = 8376mm Width = 3803mm	6.56	1.08	81.58

Table 1. Data of dead and live loads acting on Gallery 4

Source: the own author

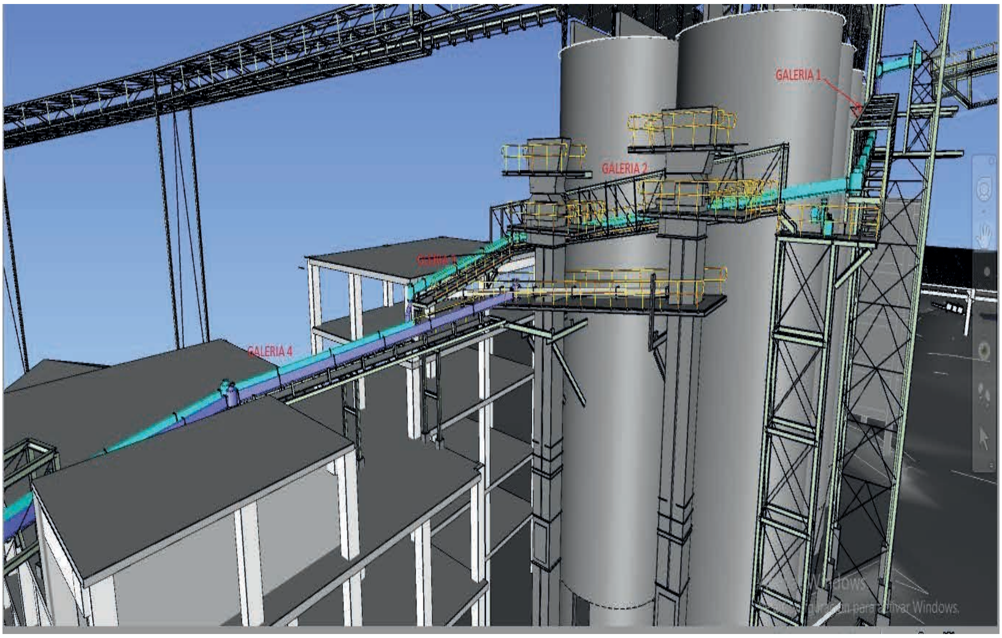

Figure 1. Location of Gallery 4 in the cement transportation project

Source: the own author

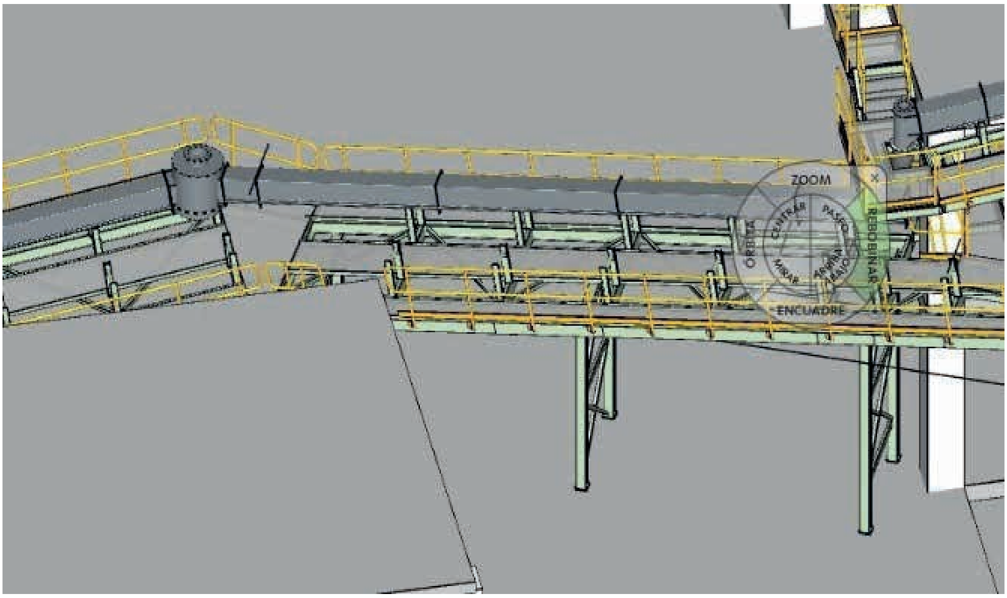

Figure 2. Sections of Gallery 4.

Source: the own author

Figure 3. Support supports of Gallery 4.

Source: the own author

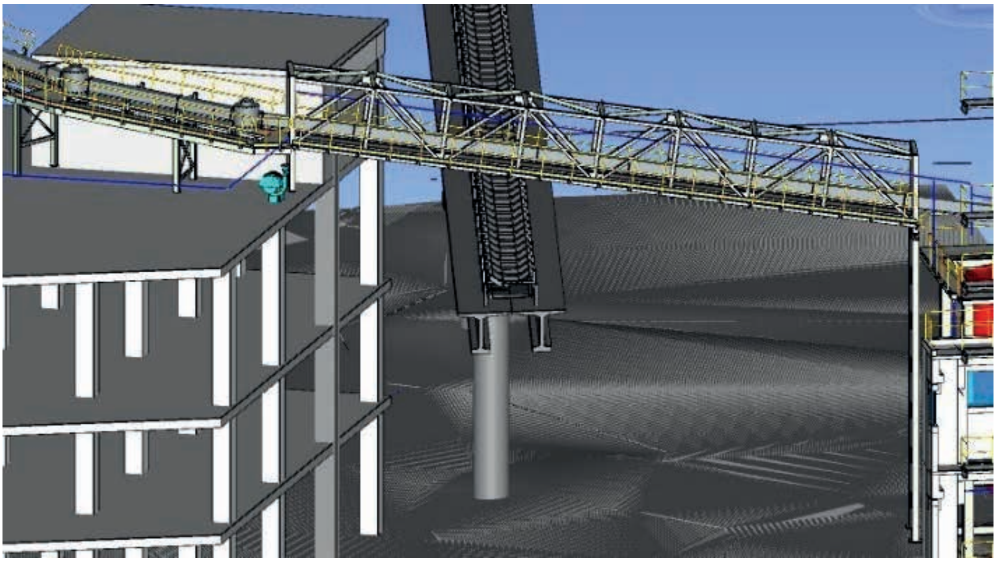

Figure 4. Location of Gallery 4 with Gallery 5.

Source: the own author

supports A, B, C, D. and E; Its calculations and results are presented in Table 2. The theoretical foundation to find the reactions A, B and C in the first section of Gallery 4 has been to apply the Theorem of the 3 moments [1].

It is important to note that the entire gallery 4 has already been calculated for the loads indicated in the project plans, therefore, the construction forms have already been designed and if they are not presented in this document it is because the purpose of this calculation report is only show the final data to later verify the way to anchor the structures on the roof of the existing building

The results of the supports presented in Table 2 raise the possibility of anchoring the supports or structural supports with 2 or 4 columns, in order to adequately distribute the load on the roof of the existing building. Evaluating said table, it is observed that support B is critical due to the greater load it supports, so a structural support with two support columns would apply an area on the roof that must support 58.50 kN per column.

DESIGN OF THE SUPPORT BASE OF GALLERY 4

Gallery 4 is made up of various elements necessary for the transport of cement through square ducts based on the use of pneumatic transport, it also has three inspection floors and safety railings supported on a structural base of the braced frame type with a length of 8376 mm and 3803 mm wide; which is shown in figures 6 and 7.

To design and evaluate this braced frame that serves as a support base, the analysis for resistance to stress and deformation was applied [2] and for the calculation by welded joint [3] the cord was analyzed for the most critical zone determined by computational methods [4]

Next, it is presented in figures 8 and 9; the constructive forms of the Support Base and Table 3 shows the general dimensions of the Support Base of Gallery 4.

For the resistance analysis, the most critical zone for stress and deformation is determined; the detail of the calculation is presented below:

ANALYSIS BY COMBINED EFFORTS

The existing distributed load is initially applied on the C6" x 8.2 beam that comes from the Gallery 4 analysis; where their reactions in the supports were presented in table 2 and the maximum value of the reaction R_2 = 117.00 kN; it will present a critical bending effort between supports 2 and 3. In addition, the acting load will present a transversal shear effort on the beam of the Support Base in the area between supports, therefore, there is a state of combined efforts.

<u>Final calculation of the C8" x11.5 profile of the Support Base</u>

For the previous assessment of the stress-strain analysis; the combined load system on the support beam has to be determined, which will be resolved by the Von Mises (VM) theory [1] which presents the following form and material data:

Transverse shear force: $\tau_{ct} = \frac{V \cdot Q}{I \cdot t}$ (1)

Bending effort: $\sigma_f = \frac{M \cdot y}{I}$ (2)

Equivalent effort VM:

$$\sigma_e = \sqrt{\sigma_f^{\,2} + 3 \cdot \tau_{ct}^{\,2}} \quad (3)$$

Permissible stress of the material: $\sigma_{F\ adm.}$= 250 N/mm ^{2}

Structural steel A-36: E = 2.1 x 10 ^{5} N/mm ^{2}

Beam length between supports: L = 3000 mm

Replacing the values obtained in the expressions proposed, the initial data for the C6"x 8.2 results is obtained, which failed, which is why the resistant inertia was increased and the C8" x 11.5 profile was obtained, which meets and results rum are presented in tables

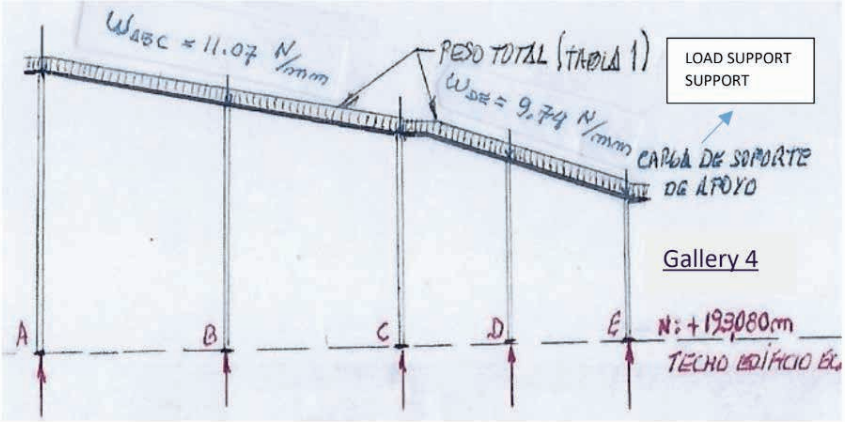

Figure 5. Location of the supports for Gallery 4.

Source: the own author

Gallery 4 of broken length of 25,055 mm	Support A Total (kN)	Support B Total (kN)	Support C Total (kN)	Support D Total (kN)	Support E Total (kN)
L = 16679mm Width = 3020mm	36.92	117.00	35.62		
L = 8376mm Width = 3803mm				41.54	41.29

Table 2. Data of dead and live loads acting on Gallery 4

Source: the own author

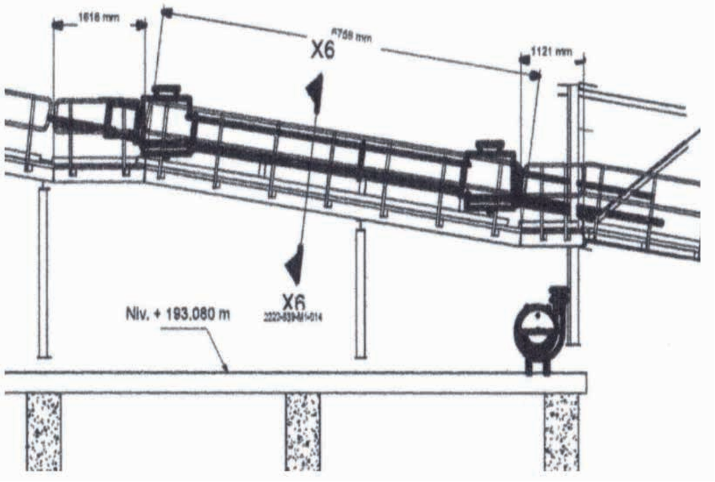

Figure 6. Side view of Gallery 4 (Section 2).

Source: the own author

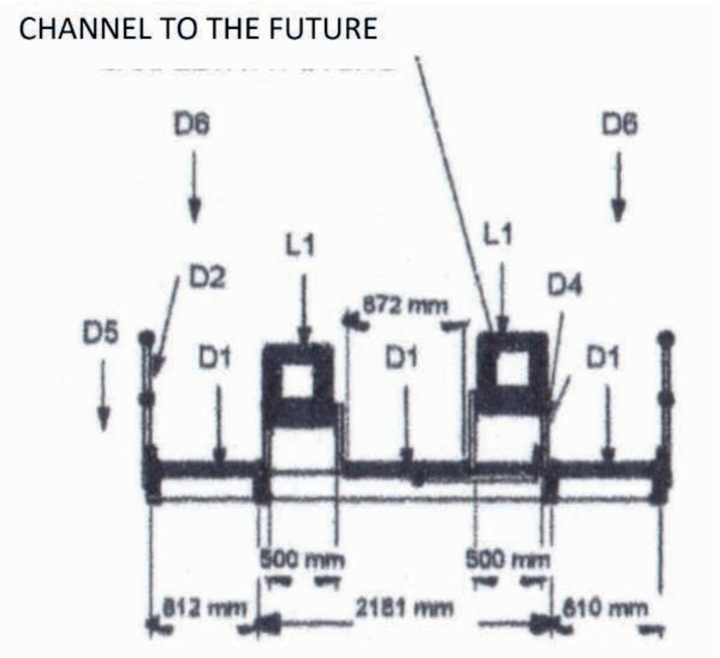

Figure 7. Section X6 - X6 of Gallery 4 (Section 2).

Source: the own author

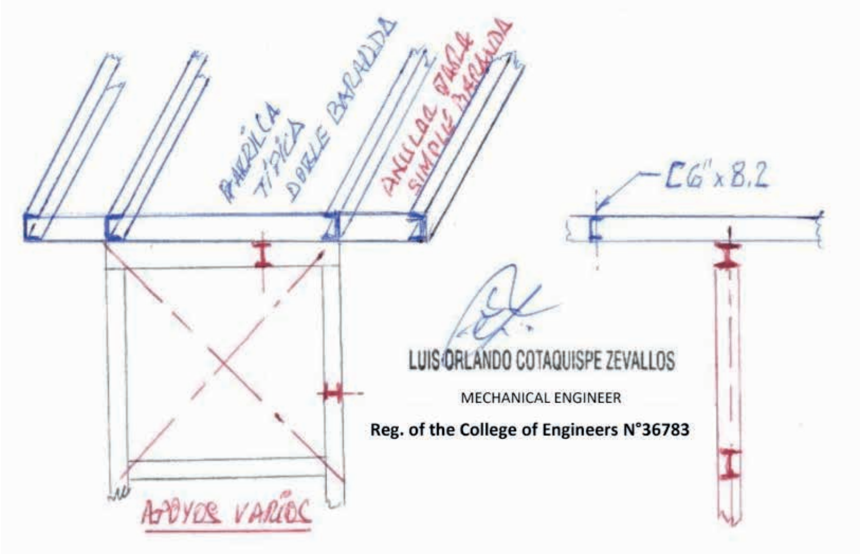

Figure 8. Projection of the support base of Gallery 4.

Source: the own author

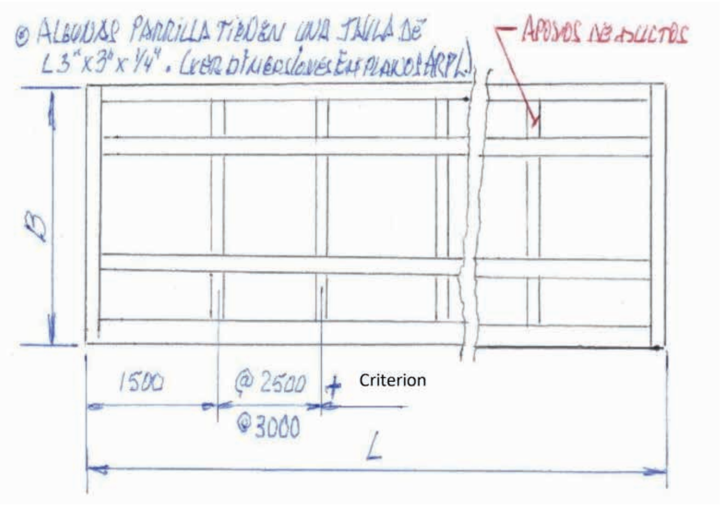

Figure 9. Plan view of the Support Base for Gallery 4.

Source: the own author

Gallery	B(mm)	L(mm)
No.1	1590	14765
No.2	1490	20535
No.3	1500	9100
No.4-1	3020	16679
No.4-2	3803	8376
No.5	3240	20503

Table 3. General dimensions of the Project Galleries.

Source: the own author

Gallery 4 Central	V (kN)	*I = 4C* (mm $^{4)}$	*Y/t* (mm)	*M* (kN.m)	*Q* ($^{mm3)}$
C8"x11.5	50.66	5.43x10 ^{7}	101.6 / 5.6	109.17	133391

Table 4. Data of the beam and its efforts.

Source: the own author

τ_{ct} (N/mm $^{2)}$	σ_f (N/mm $^{2)}$	σ_e (N/mm $^{2)}$	$\sigma_{F\ adm.}$ (N/mm $^{2)}$	*FS*
11.1	204.4	205.3	250	1.22

Table 5. Results of the Beam for the Support Base.

Source: the own author

4 and 5;

STRAIN ANALYSIS

To evaluate the structural deformation of the Support Base of Gallery 4 (see figures 8 and 9), the C8" x 11.5 profile is considered as the main element of the Base and it will be analyzed as a distributed load system without considering the structural profiles yet. inner reinforcement. Therefore, expressions 4 for the bending moment and 5 for the deformation will be applied for the analysis; both deduced from figure 10

$$M = \frac{w \cdot L}{8} \qquad (4)$$

$$\delta = \frac{5 \cdot w \cdot L^4}{384 \cdot E \cdot I} \qquad (5)$$

Then in tables 6 and 7 the results of the analysis by structural deformation of the Support Base are presented considering the main and secondary elements located as observed in figure 10, then this value is compared with the ASTM recommendation [5] on the subject of critical stiffness for structural constructions and whose recommended comparison value is R_{ASTM} = 0.001

WELD ANALYSIS

Due to the location of the distributed loads with respect to the structural frame that serves as the Support Base, a state of critical combined stresses will be obtained on the corner of the welded joint (see figures 8 and 9). The dimensions of the Support Base correspond to the AWS recommendation to consider the welded joint as a line [6]. Figure 7 shows the distances of the state of charges in relation to the area of the weld seams. Then, considering the welded joint as a line, its inertia is evaluated according to figure 11. The geometry and the loads subject the critical zone to bending and cutting, therefore it is necessary to evaluate the equivalent stress in the critical chord.

Therefore, the expressions for a weld evaluation as a line are presented below:

Weld as line: $A=2.a[b+2.d]$ (6)

Centroid: $x=\frac{b}{2}$; $y=\frac{d}{2}$ (7)

unit inertia: $I_u=\frac{d^2}{2}[3.b+d]$ (8)

When the combined load acts, it is considered the HZ load case and the C8" profiles are made of St.37 (A-36) steel. The load values are as follows:

- M_f=109.17 *kN-m*
- *V*=50.66 *kN*

Now the values of each acting stress are determined based on the data presented and finally the calculation of combined stresses, so it will be necessary to evaluate said state through its expression of equivalent stress (TMEN) [7] ;

$$\sigma_{eq} = \frac{1}{2}\left\{\sigma_{fs} + \sqrt[2]{\sigma_{fs}^2 + 4\tau_{cs}^2}\right\} \qquad (9)$$

In the <u>case of inflection</u> [M_f=109.17 *kN-m*]; will have the following:

$$\sigma_{fs} = \frac{M_f \cdot e}{I}$$

Where $I = I_u.a$

$$I_u = \frac{d^2}{6}(3b + d);$$

for the geometry of the joint (see figures 8 and 11)

Substituting you have $\sigma_{fs} = \frac{257}{a}$

Evaluating the weld bead, the following is obtained:

$$a = 3\,mm \quad \rightarrow \quad \sigma_{fs} = 85.67\ N/mm^2$$
$$a = 6\,mm \quad \rightarrow \quad \sigma_{fs} = 42.84\ N/mm^2$$

In the <u>case of the cut</u> [*V*=50.66 *kN*]; will have the following:

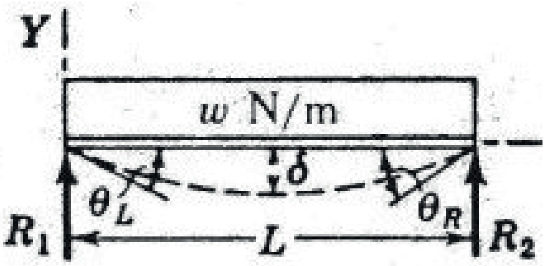

Figure 10. Analysis for deformation [1]

Gallery 4 Central	*I* = 4*C* (mm $^{4)}$	*L* (mm)	*E* (N/mm ^{2})	*W* (N/mm)
C8"x11.5	5.43x10 ^{7}	3000	2.1x10^{5}	48.5
C8"x11.5	5.43x10 ^{7}	1800	2.1x10^{5}	48.5

Table 6. Data of the main beam of the Support Base.

Source: the own author

Gallery 4 Central	*L* (mm)	δ (mm)	$R_T = _{\delta T} / L$	$R_T \leq _{ASTM\ R}$
C8"x11.5	3000	4.49	0.0015	≤0.001
C8"x11.5	1800	0.58	0.00032	≤0.001 _

Table 7. Results of the rigidity of the Support Base

Source: the own author

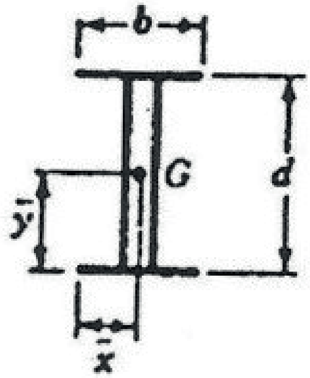

Figure 11. Weld as line [6 ; 8]

$$\tau_{cs} = \frac{V}{2\cdot a\cdot(b+2d)}$$

Substituting you have $\tau_{cs} = \frac{47.49}{a}$

Evaluating the weld seam we have the following:

$$a = 3\,mm \quad \rightarrow \quad \tau_{cs} = 15.84\,N/mm^2$$
$$a = 6\,mm \quad \rightarrow \quad \tau_{cs} = 7.92\,N/mm^2$$

Finally by substituting the equivalent stress for the most critical thickness as ***a=3mm;*** you have:

$$\sigma_{eq} = 88.5\,N/mm^2$$

Verifying if it resists, it is compared with the values of table 8 for $\sigma_{s\,Adm}$;

So you get; $\sigma_{eq} \leq \sigma_{s\,Adm}$

$$88.5\frac{N}{mm^2} \leq 130\,\frac{N}{mm^2}$$

DESIGN OF THE SUPPORTS OF THE GALLERY 4

Figure 5 shows the supports of Gallery 4, the most critical due to load and height being the so-called support B (section 1). The load is 117.00 kN (see table 2) for a width of 2000 mm and a height of 4000 mm; which is defined in figures 6 and 8, these supports are also pivotally connected at the top with the Support Base of Gallery 4; and in the lower part they will be anchored to a structural grill that will be anchored to the existing roof. Therefore, there is a flat structural support with 2 supports with an average slenderness in relation to its working section.

The structural supports were designed with a W6"x20 beam and column and braced with a C6"x8.2 channel, lightened and resistant to structural buckling. The own weight of the structural Support B is 5.10 kN

For this analysis and calculation, the effect of axial compression load due to external load in the elastic field and the effect of the weight of support B itself are considered, for which the columns are loaded from the top to the concrete base, Initially, unfavorable conditions are considered, that is, the reinforcements of the secondary structure are not considered (inclined braces of *L* 3" x 3" x ¼"); but if horizontal reinforcements are considered to limit the buckling length.

In other words, the length of the structural Support B will be divided between 2 spaces (see figure 12), therefore, L_P = 2000 mm and the total load on each column is 61.05 kN.

The methodology requires evaluating only compression loads, analyzing the types of support and the minimum radius of gyration of the area of the selected profile, then the following must be met:

$$\omega.\sigma \leq \sigma_{F\,adm}$$

This expression is the one that verifies the buckling in structures according to the European method [9];

$\sigma_{F.adm}$= 140N/ ^{mm2}

Besides σ= $_{Fc\,/\,AW}$

Where

F_c = critical compression force at support

A_W = area of the structural profile

In addition, tables 9 and 10 will be used for the structural calculation by buckling (DIN 4114 standard "ω" method). After table 9, the value of $\bar{\omega}$(European method) is evaluated; for which the slenderness $\lambda_W = L_P / i$ *must be assessed* for the profile analyzed according to the standard.

Next, a summary is presented in tables 11 and 12, updated through an iterative work and, as can be seen, the profiles for the 2 columns are guaranteed by buckling.

As a final result, the W 6" x 20 profile is considered for the 2 columns and the upper beam; being braced along its horizontal length with a 6" x 12 W profile and its inclined

Line	Cord Type	Effort class	Class St 37 Load case H	HZ
1	100% Xray checked butt bead	Axial traction and flexural traction	160	160
2		Axial compression and compression with bending	140	160
3		Cut	90	105
4	Butt bead not x-rayed	Traction, axial compression and with flexion	140	160
5		Cut	90	105
6	Butt bead not ray checked	Axial traction and flexural traction	110	130
7		Axial compression and compression with bending	140	160
8		Cut	90	105
9	Angled bead	Traction, compression, sliding	90	105
10	Angled chord in bending resistant beam splice	Principal effort	110	130
11		Cut	90	105

Table 8. Permissible stresses according to DIN 4100, see line 10 [8]

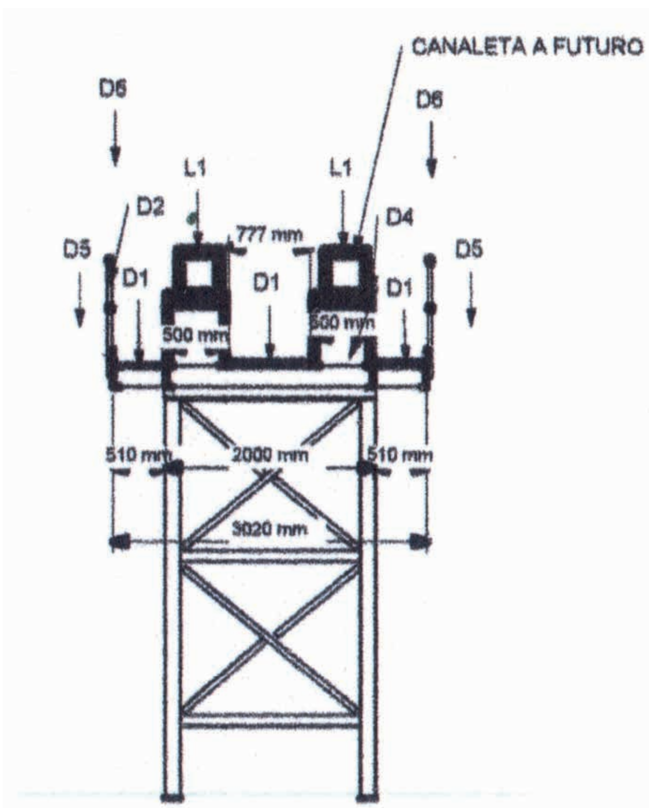

Figure 12. Support B of Gallery 4 (Section 1).

Source: the own author

λ	0	1	2	3	4	5
20	1,00	1,00	1,00	1,00	1,01	1,01
30	1,03	1,03	1,04	1,04	1,04	1,05
40	1,07	1,07	1,08	1,08	1,09	1,09
50	1,12	1,13	1,13	1,14	1,15	1,15
60	1,19	1,20	1,20	1,21	1,22	1,23
70	1,28	1,29	1,30	1,31	1,32	1,33
80	1,39	1,40	1,41	1,42	1,44	1.46

Table 9. Values of " $\bar{\omega}$" for St.37 profile; as a function of λ [9]

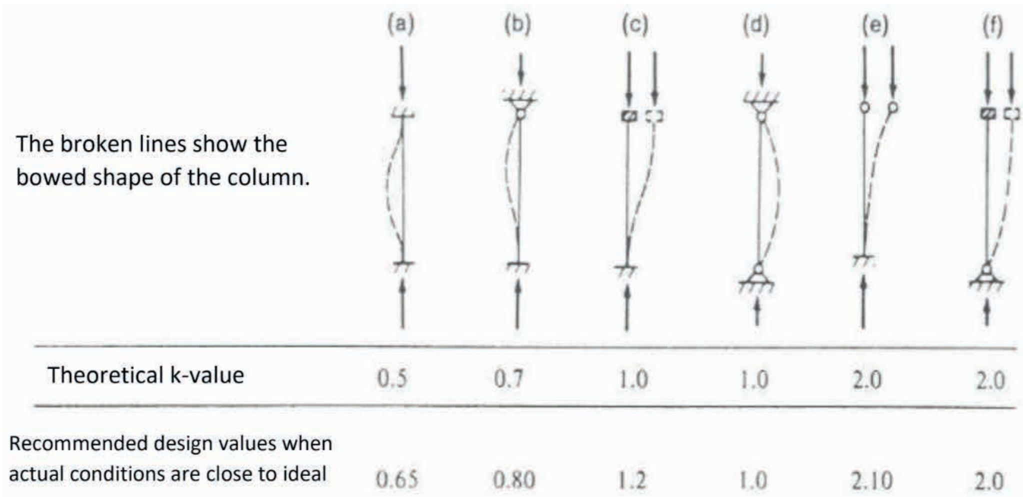

Table 10. effective column lengths [9]

2 columns support. Profile Type	A (mm2)	$P_{crit\ support}$ (kN)	L_P (mm)	λ	ω Table 9
W 6" x 20	3806	61.05	2000	53	1.14

Table 11. Buckling column characteristics.

Source: the own author

σ_c (N/mm$^{2)}$	σ_c xω (N/mm$^{2)}$	≦ σ_{adm} T:200°C (N/mm$^{2)}$	*Factor of Overload*
16.1	18.4	140	7.61

Table 12. Calculation of columns to structural buckling

Source: the own author

bracing will be a 3" x 3" x ¼" angular profile; joined by permanent or removable union to guarantee a secure support to Gallery 4.

DESIGN OF THE GRILL TO SUPPORT THE EXISTING ROOF

Based on the 20-year age of the civil works, it was decided to place the critical support supports on a structural grid in order to reduce the anchor points of the structural supports A, B, C, D and E. It is important to note that with the plans of the civil works, the location of the beams and columns involved in the route of Gallery 4 was defined.

It is also important to point out that section 1 of Gallery 4 was the critical reason why the constructive form of the structural Grill was designed there, which will be anchored to the existing roof and will only serve as anchorage for the first 4 support supports (see figure 13). The calculation in summary is analogous to the one developed in section 4.1; but in this case, only the pure bending beam W is evaluated in the upper flange according to formula (2), because the lower flange is supported and anchored to the roof, therefore, only tables 13 and 14 containing the analysis will be presented. and results for the case of the support structure subjected to pure bending in two planes.

The result of this analysis shows that along the Grid there is the most unfavorable state of loads and that from the W8" x 18 profile, safe solutions can be given for the support Grid, in the face of a complicated geometry, because it has to respect the civil works and their locations of columns and reinforced concrete beams. It is appropriate to point out that the support grid was designed for a single type of profile in its entire geometry, which is shown in figure 13.

CONCLUSIONS

- The most complicated part of the circuit of a pneumatic transport project has been presented, destined to increase the production of cement, through a circuit of load-bearing galleries that support the square gutters. Table 3 shows the lengths of the Galleries that imply a total length of 90 meters destined for the transport of the cement to the Buffer Silo (see figures 1, 2, 3 and 4). The area of interest is represented by Gallery 4, which is a construction of two sections according to the approved circuit and its support system is located on the roof of an existing civil work, which conditions the analysis and calculation presented in this document..
- The analysis of Gallery 4 highlights the various constructive forms in the subject of structures, where determining the acting loads (see table 1) and obtaining the reactions in the supports (see table 2) have been important to later determine the efforts acting and deformations in the critical zone (see tables 5 and 7). Therefore, there is a structural design of the Support Base (see figures 7 and 8) whose results comply with the indicated standards.
- A fundamental issue in all structural design is the analysis and calculation of the weld in Gallery 4, the critical component being the Lower Support Base evaluated by channels and reinforced with angular profiles, the criterion has been to evaluate the weld seam as a line due to the dimensions of the structure and the state of loads based on the equivalent effort (see figure 11). The results present the initial alternative of a minimum bead of 3 mm; which will be contrasted with the thickness of the profiles that make up the joint.
- The support supports of Gallery 4

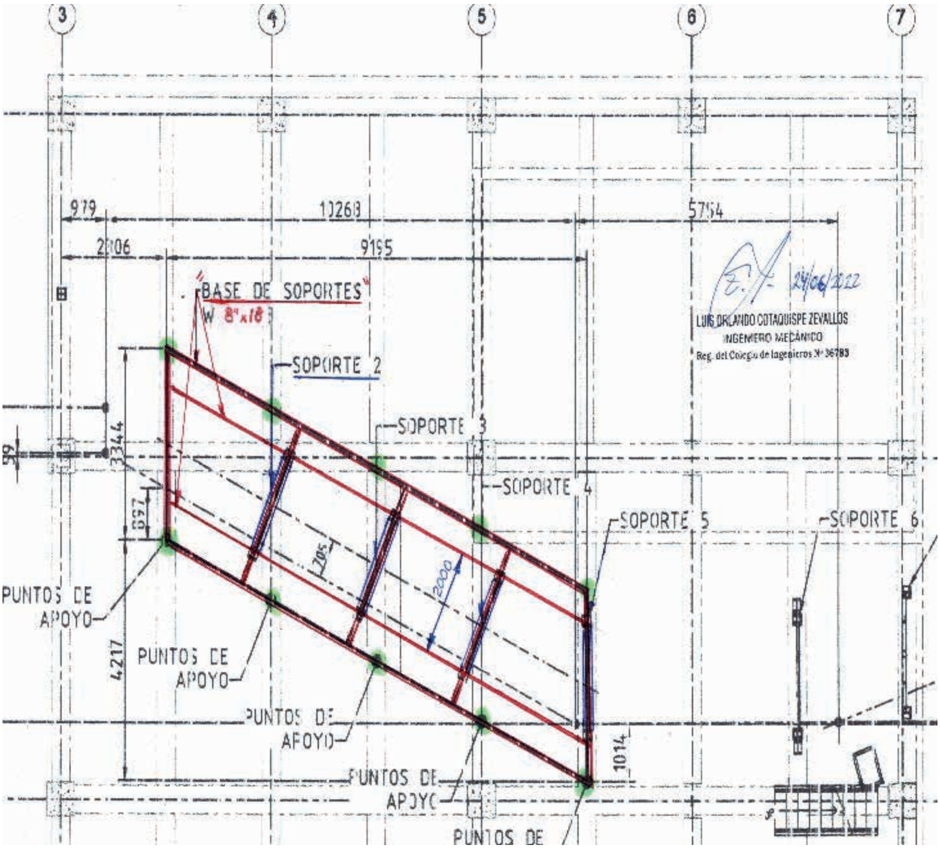

Figure 13. Support grid for Gallery 4 (Section 1).

Source: the own author

Grill Ceiling	*I* (mm^4)	*Y* (mm)	*M* (kN.m)	σ_f (N/mm $^{2)}$)	$\sigma_{F\,adm.}$ (N/mm $^{2)}$)
W8"x18	2.58x107 -	103.4	61,585	246.8	250
W8"x24	3.45x10 ^{7}	100.7	61,585	179.8	250

Table 13. Beam and stress data along the Grid

Source: the own author

Grill Ceiling	*I* (mm$^{4)}$	*Y* (mm)	*M* (kN.m)	σ_f (kg/mm $^{2)}$)	$\sigma_{F\,adm.}$ (kg/mm $^{2)}$)
W8"x18	2.58x107 -	103.4	35,666	142.9	250
W8"x24	3.45x10 ^{7}	100.7	35,666	104.1	250

Table 14. Beam and effort data in the direction of Support B

Source: the own author

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.3173182302068

are subjected to compression (see figure 12) and its fundamental calculation is to determine its stability under load. Therefore, based on sizing by Buckling, it was determined that the support must have two columns and the greatest height to verify its slenderness, obtaining the appropriate type of profile. The way to connect these supports to the existing floor was also analyzed, for which a structural support grid was designed and calculated (see figure 13) that connects the 4 support supports for joint work that will relieve the work of the existing roof. The results of the profiles evaluated for the Grill are presented in tables 13 and 14

REFERENCES

[1] J. M. Gere, S. Timoshenko. "Resistencia de Materiales". 5ta edición. 2012. [PDF]. Disponible en: https://www.amazon.com

[2] J. McCormac. "Diseño de Estructuras de Acero". 4ta. edición. 2013. [PDF]. Disponible en: https://www.academia.edu

[3] Norma E.090 – Estructuras Metálicas. 2018. [PDF]. Disponible en: https://www.ici.edu.pe

[4] Software de aplicación SAP 2000 – Estructuras Metálicas. Disponible en: https://www.software-shop.com

[5] AISC 2013 "Manual de Diseño para la Construcción con Acero". [PDF]. Disponible en: https://www.ahmsa.com

[6] P. Ringegni. "Cálculo de Uniones Soldadas" 2013. Disponible en : https://www.acero.ing.unlp.edu.pe [PDF].

[7] G. Niemann. "Elementos de Máquinas". Vol. 1. 2017. [PDF]. Disponible en: https://www.amazon.com

[8] Norma DIN 4100. "Tensiones admisibles en uniones soldadas". 1968. [PDF]. Disponible en: https://www.es.scribd.com

[9] Norma DIN 4114. "Dimensionado por Pandeo". 1953. [PDF]. Disponible en: https://www.scribd.com