Pedestrian Bridge Design with IPE beams

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Abstract

The objective of this project is to design a pedestrian bridge that ensure the security of the people who want to cross the street at Las Americas Avenue in San Juan de Pasto, Colombia. In the first place, a hydraulic platform at the ends of the structure to help disabled people to cross the bridge will be used. Also, the structural analysis will be used to solve the structure with Cross method. Finally, to obtain the deflection of the beam Python software will be used.

Key words: pedestrian bridge, hydraulic cylinder, loads, Cross Method, Python.

Introduction

Civil engineering is considered a career with high demand, because it focuses on trying to solve construction problems. An example of this are pedestrian bridges; in general, they are structures placed correctly in specific places in order to provide security to people who transit them; this type of structure can be built with different types of materials like beams which can be made of materials such as concrete or steel.

An investigation was carried out near the central area of the city of Pasto; the results of the rate of accidents that were obtained are very high. A possible solution to reduce this type of accident is to design a pedestrian bridge using IPE beams. To carry this out, the implementation of hydraulic platforms will be mainly taken into account; in addition, the behavior of the structure due to loads will be studied with the Cross method; also the deflection of the beams will be obtained numerically through the Runge-Kutta method in the Python software.

Problem Statement

There is great circulation of people in the central area of the city of Pasto on Las Américas avenue, because this is a commercial area. The problem is that the road is made up of two lanes, hence people put their lives at risk when crossing it.

Objectives

General Objective

To carry out the design of a pedestrian bridge with IPE beams for the benefit of the community of Las Américas avenue in the city of Pasto.

Specific Objectives

- To use a hydraulic platform at the ends of the structure.
- To analyze the structure applying the Cross method.
- To analyze the deflection of the beam through the Runge-Kutta method, using Python software.

Methodology

To carry out this project, initially an enquiry in designs of lifting platforms was run. The dimensions of the platform were taken from an end-of-degree project entitled *Diseño, calculo y dimensionamiento de una plataforma elevadora móvil de personal con accionamiento hidráulico* by engineer Pablo Martinez del Pozo (2012).

The symmetry of the structure was taken into account to obtain the maximum deflection of the beams; considering from the calculation of a single element, it can also be determined for the rest. However, through Python software and Runge-Kutta method, the solution of deflection was found estimating initial values and the distance where the deflection will be maximum. Finally, the moments at each node of the portico and the vertical and horizontal reactions were found, and the moment diagram was obtained.

Results

The pedestrian bridge will be located on Las Américas avenue in the city of Pasto in the department of Nariño and its design is constituted with the dimensions presented in Table 1.

Table 1. *Bridge dimensions*

Variable	Equivalence
a	2,0 m
l	13,5 m
h	6 m

One of the main characteristics of the structure is the absence of stairs, which is why two lifting platforms will be installed at each end, each of them is 2 meters long and 1.5 meters wide.

The hydraulic system consists of a motor pump, a hydraulic fluid tank, safety valves, the fluid under pressure and four hydraulic actuators. The pump of this system are two external rotary gears hydrostatic within a vacuum chamber, which can be used as a motor because of the gears rotate in one direction. Its function is to transform mechanical energy into hydraulic energy, driving the hydraulic fluid in the system.

The reservoir must be sealed to prevent contamination of the fluid, but at the same time it must have a ventilation with a built-in filter to allow air to enter and exit. When the fluid enters the system again, it first passes through a filter where residual impurities are stopped.

Pressure limiting valves perform functions such as limiting the maximum pressure of a system or regulating the reduced pressure in certain parts of a circuit. Later the control valves are used in hydraulic circuits to control the direction of the flow; in this case, using 4/3 valves because they are used to control the operation of double-acting cylinders.

The main function of hydraulic fluid is to transmit the energy generated by pressure; the transmission of this hydraulic force requires a fluid that resists compression and easily flows in the hydraulic circuit. The machinery used in hydraulic systems is generally high pressure, so all its moving parts must be perfectly lubricated to minimize friction and wear. The fluid used must dissipate the heat generated in the hydraulic system and it has minimal variation in viscosity with temperature. Hydraulic oil ISO 68 Chevron with HM classification will be used. This is a mineral oil with anti-wear additives, oxidation and corrosion inhibitors. The quart of this oil has a value of $16000 Colombian pesos.

Finally, the hydraulic actuator is the component of the system where mechanical work is produced by the action of hydraulic fluid. For the hydraulic unit of the platforms, a double-acting cylinder will be used, called in this way because it is powered by hydraulic fluid in both directions.

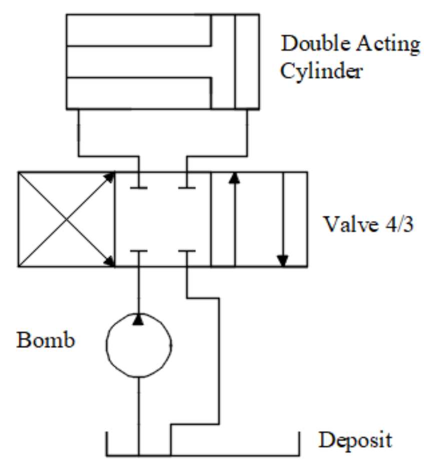

Figure 1. Hydraulic system.

To find the value of the maximum deflection of the beams, it must be taken into account that the bridge is made up of two porticos; therefore, the calculations that are made in the middle of the structure are valid for the other half; this is due to the symmetry of the structure. Based on the previous information, the value of dead and live loads must be calculated. Initially, the dead load will be calculated, considering the weight of the bridge slab and all the elements on it.

The material from which the bridge slab is made is steel; its density is 7800 kg / m3 and to calculate the volume it is estimated that this element is a rectangular cube.

Table 2. *Plate dimensions*

Variable	Equivalence
a	2,00 m
l	13,50 m
h	0,01 m

$$V = 0{,}27\ m^3$$

$$m_p = 2106 \text{ Kg}$$

Next, the mass of the handrails must be calculated.

Table 3. *Handrail dimensions*

Variable	Equivalence
hph	13,50 m
hpv	1,20 m
r	0,03 m

$$V_{ph}=0{,}038\ m^3$$

$$V_{pv} = 0{,}0034\ m^3$$

Vph is the volume of a horizontal handrail and Vpv is the volume of a vertical one. Vph times 6 and Vpv times 20 because these are the total units on the structure.

$$V_T=0{,}297 \text{ m}^3$$

$$m_{pa}= 2316{,}77 \text{ Kg}$$

For the lighting of the structure, seven lamps will be distributed uniformly, which have a mass of 23.2 kg, therefore to find their total mass, simply multiply this value by the number of lamps.

$$m_{la}= 162{,}4 \text{ Kg}$$

The values of the masses are added together and obtain the weight with a gravity of 9.81 m/s^2.

$$Fw = 44980{,}54 \text{ N}$$

For live load, the design criteria and parameters for pedestrian bridges in Colombia must be taken into account, since there it is stipulated that the value of this load corresponds to 450 kg/m^2, and the result must be multiplied by the number of squeare meters of the plate.

$$Fw = 4414{,}5 \text{ N}/m^2$$

$$Fw=4414{,}5 \text{ N/m}^2 \cdot 27\ m^2$$

$$Fw = 119191{,}5 \text{ N}$$

Finally, to find the total load, the value of the dead load and the live load must be added.

$$F_{WT}= 164172{,}04 \text{ N}$$

This total load found must be divided by the number of beams, which in this case are three, but these, in turn, are divided by a column; therefore, the result obtained is divided by two again, and the value is below.

$$Fw = 27362{,}01 \text{ N}$$

This load result must be converted to distributed load; so, it will be divided by 6.75 m.

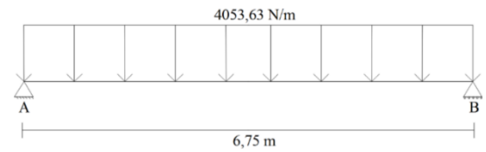

Figure 2. Beam.

Equation 1 is applied to make the summatory of moments at point A and find the reaction of the mobile support at B.

$$\sum M_A=0$$

$$(R\_A \cdot 6{,}75)-(F\_Wd \cdot 6{,}75 \cdot 3{,}375)=0 \quad (1)$$

$$RB=13681 \text{ N}$$

Equation 6 is applied to perform the summatory of forces on the Y axis and obtain the reaction at the fixed support at A.

$$\sum F_y = 0$$

$$-(FWd \cdot 6{,}75) + R_B+R_A=0 \quad (2)$$

$$R_A= 13681 \text{ N}$$

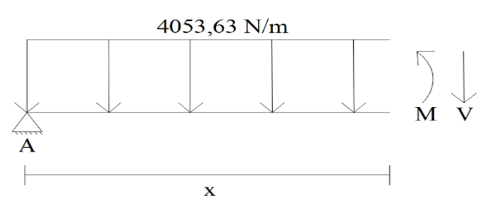

Figure 3. First cut

Summatory of moments is performed on the right side to find the equation of moments.

$$\sum M = 0$$

$$M + (F_{Wd} \cdot x \cdot x/2) - (R\_A \cdot x) = 0 \quad (3)$$

$$-2026\, x^2 + 13681x = M$$

Summatory of forces on the Y axis is performed to obtain the shear equation.

$$\sum Fy = 0$$

$$R_A (F_{Wd} \cdot x) - V = 0 \qquad (6)$$

$$V = 13681 - 4053{,}63\,x \qquad (4)$$

Equation 4 equals zero and the variable x is cleared, which would represent at what distance from support A, the maximum moment occurs.

$$13681 - 4053{,}63\,x = 0$$

$$x = 3{,}375 \text{ m}$$

The value of x found above is replaced in equation 3 to find the maximum moment.

$$-2026{,}81 \cdot (3{,}375)^2 + 13681 \cdot 3{,}375 = M$$

$$M_{max} = 23086{,}74 \text{ N.m}$$

The beam is made of A36 steel which has a yield stress (Fy) of 240 MPa, since it is going to work with a factor of safety of 2, equation 5 must be applied to obtain the admissible stress.

$$\sigma_{adm} = \frac{Fy}{FS} \qquad (5)$$

$$\sigma_{adm} = 120 \text{ MPa}$$

To find the shear stress, equations 6 must be applied, knowing that the numerical value is the Von Mises failure criterion.

$$\tau_{adm} = \frac{\tau}{FS}$$

$$\tau_{adm} = 67{,}2 \text{ MPa}$$

To know the admissible values of both stress and shear stress, the information in the IPE 220 profile will be used to know if it has the capacity to withstand the stresses caused by loads, for which equation 7 must be applied.

$$\sigma = \frac{M_{max} \cdot Y}{I} \qquad (7)$$

$$\sigma = \frac{23086740 \cdot 110 \text{ mm}}{(2770 \times 10^4)}$$

$$\sigma = 91{,}68 \text{ MPa}$$

Because the result obtained is less than the allowable stress, we can continue to find the value of the shear stresses with equation 8.

$$\tau = \frac{Vmax}{tw \cdot hi}$$

$$\tau = \frac{27362{,}003}{5{,}9 \cdot 202}$$

$$\tau = 22{,}96 \text{ MPa}$$

With the results found, it can be determined that the IPE 220 profile will be able to withstand the efforts without reaching failure. Its dimensions are shown in figure 4.

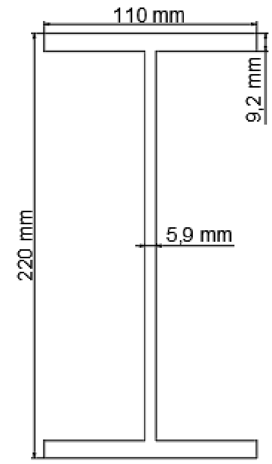

Figure 4. Beam IPE 220.

In Figure 5, a portico can be seen which make up the structure. Through the Cross method, this system will be solved, considering that the total load previously obtained must be converted to distributed load.

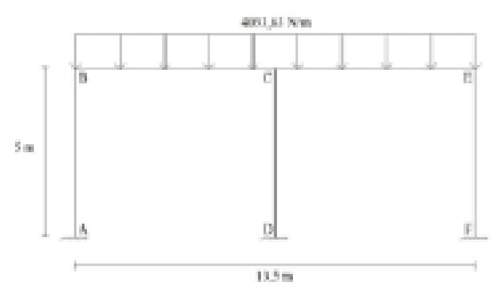

Figure 5. Portico.

For the beams, this inertia is defined as 2770 cm^4, but for the columns that are considered as rectangular cubes with a profile of (11x11) cm, Equation 9 is used.

$$I = \frac{b \cdot h^3}{12} \qquad (9)$$

$$Ic = 1220{,}08 \text{ cm}^4$$

Knowing the inertia values for each case, we proceed to calculate the stiffnesses with equation 10.

$$K=\frac{I}{L} \tag{10}$$

$$K_{AB} = K_{DC} = K_{FE} = 2{,}44$$

$$K_{BC} = K_{CE} = 4{,}10$$

With the above information and applying equation 11, the distribution coefficients are obtained at each of the nodes, these values can be verified when summing up all the coefficients that the result is 1, and 0 when there are embedded supports.

$$\delta=\frac{Kij}{\sum Ki} \tag{11}$$

$\delta_{AB} = 0$

$\delta_{BA}= 0{,}37$ δ_BC=0,63

$\delta_{CB} = 0{,}39$ δ_CD=0,22 δ_CE=0,39

$\delta_{DC} = 0$

$\delta_{EC} = 0{,}63$ δ_EF=0,37

$\delta_{FE} = 0$

For this case, the load is distributed along the beam; therefore, equation 12 must be applied for both the BC and CE sections, for the EC and CB sections the value of the moments is obtained with the same equation except that with negative sign.

$$M^F = \frac{wL^2}{12} \tag{11}$$

$$M^F{}_{BC} = 15{,}39 \text{ kNm}$$

$$M^F{}_{CB} = -15{,}39 \text{ kNm}$$

$$M^F{}_{CE} = 15{,}39 \text{ kNm}$$

$$M^F{}_{EC} = -\ 15{,}39 \text{ kNm}$$

Subsequently, a moment distribution must be made taking into account both the distribution coefficients and the embedment moments. Also, the transmission coefficient that corresponds to a value of 0.5. Table 4 shows the processes.

Table 4. *Moments Distribution*

	Joint A	Joint B		Joint C			Joint E		Joint F	Joint D
	AB	BA	BC	CB	CD	CE	EC	EF	FE	DC
δ	0	-0,37	-0,63	-0,39	-0,22	-0,39	-0,63	-0,37	0	0
M^F	0	0	15,39	-15,39	0	15,39	-15,39	0	0	0
	0	-5,69	-9,69	0	0	0	9,69	5,69	0	0
	-2,84	0	0	-4,84	0	4,84	0	0	2,84	0
	0	0	0	0	0	0	0	0	0	0
Σ	-2,84	-5,69	5,69	-20,23	0	20,23	-5,69	5,69	2,84	0

In Figure 6, both the direction and the magnitude of the moments that occur in each one of the nodes are indicated. For the central column, the moments are 0; consequently, it is not necessary to make a graphical representation.

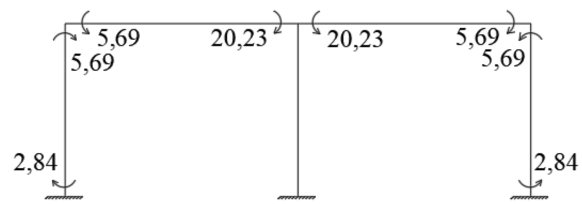

Figure 6. Moments Results

With the values of the moments at each node, we must proceed to find the reactions on both the y-axis and the x-axis.

$$R_{Ay} = 11{,}53 \text{ kN}$$

$$R_{Dy} = 31{,}67 \text{ kN}$$

$$R_{Ey} = 11{,}53 \text{ kN}$$

To verify that the above values are correct, the sum of these must be equal to the point load produced by the distributed load.

$$R_{Ay} + R_{Dy} + R_{Ey} = (4{,}054 \cdot 13{,}5)$$
$$11{,}53 + 31{,}67 + 11{,}53 = (4{,}054 \cdot 13{,}5)$$
$$54{,}73 \text{ kN}=54{,}73 \text{ kN}$$

For the first and third columns a pair of forces is needed in order to balance the system; their values can be found by adding the respective moments and dividing them by the distance of each element.

$$R_{Ax} = 1{,}71 \text{ kN}$$
$$R_{Ex} = 1{,}71 \text{ kN}$$

Figures 7 and 8 indicate the shear and moment diagrams.

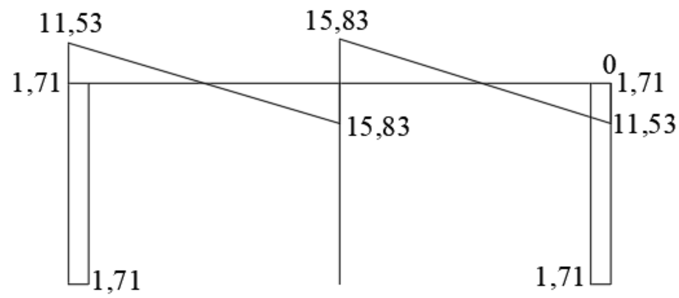

Figure 7. Shear diagram.

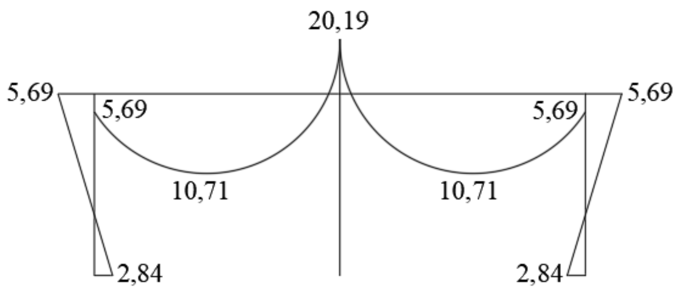

Figure 8. Moment diagram.

Finally, with Python software, a program capable of finding the value of the deflection in one of the beams with Runge-Kutta method will be design. This method is used to obtain approximate solutions to first-order ordinary differential equations; next equation must be applied because it is called the most important part of it.

$$yi+1 = y_i + (K_1 + 2K_2 + 2K_3 + K_4) \cdot h/6$$

...where **h** is the width or pitch value of the subintervals and **xf** is the distance where the maximum deflection of the beam will be presented.

$$h = \frac{x_f - x_o}{n}$$

For this case it is necessary to know the solution to the differential equation of the elastic; however, this is second order, so it must be expressed in the form of new variables.

$$\frac{d^2y}{dx^2} = \frac{M}{EI}$$

$$\frac{d^2y}{dx^2} EI = -2026{,}81\, x^2 + 13681\, x$$

We proceed to replace the value of **y** with that of **y1** and later, the new variable **y2** is expressed in terms of the derivative of **y1** with respect to **x**. This is the first function that depends on the variables x, y1, y2.

$$\frac{d^2y}{dx^2} = f(x, y_1, y_2) = y_2$$

The derivative of **y2** with respect to **x** will be considered the second function.

$$\frac{dy_2}{dx} = \frac{-2026{,}81\, x^2 + 13681\, X}{EI} = f(x)$$

When the two functions are obtained, the code must be carried out in the Python software. The result of the deflection take value of -0.01984 m. In Figure 9 it can be seen that the curve gets closer as the analytical solution.

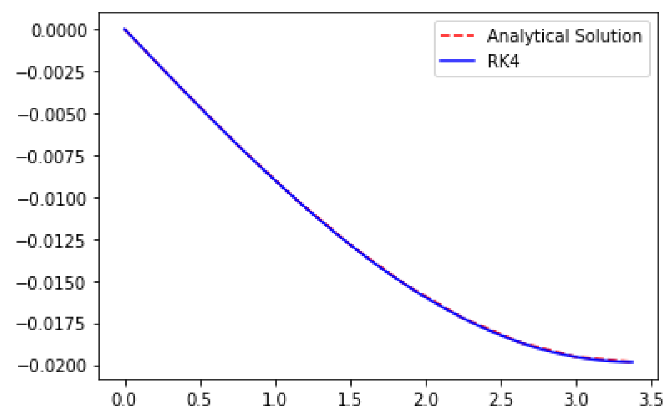

Figure 9. Runge Kutta solution with 0.001 iterations.

Analysis of Results

Commercially, it can find various hydraulic power units to be used in the lifting platforms that will be placed on the pedestrian bridge; the price of these are rounded to approximately $ 2,000,000 Colombian pesos.

Through the numerical method, a value was obtained for the deflection of the beam that is supporting one sixth of the total load to which the structure is generally subjected; the result was -0.01984 m; the negative direction indicates that the curvature of the beam opens upwards and due to the symmetry of the structure this value is valid for all beams. In turn, this quantity can vary depending on the type of profile; the inertia value and the Young's modulus according to the type of material they are made of.

Conclusions

Through thisproject, the city of Pasto seeks to promote the use of lifting platforms for pedestrian bridges, since by occupying less space in the city, it would generate that in the future, the space used for stairs may become a better used space.

The deflection of the beam found with Runge-Kutta method is closer to the analytical value of the deflection, because they converge faster; that is, they need smaller steps to find the correct answer.

The Cross method is considered an approximate method to solve complex structures. The application of this method in the project was important because the response of the nodes to the loads to which the structure is subjected can be known.