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Design of Pedestrian Bridge using Prestressed Beams and Decks at Kano University of Science and Technology, Wudil Campus's Main Gate

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Abstract - *Gaya Road is a way on which motorists usually travel at a high speed which poses danger to the lives of many students who cross the road during the school hours, because of that, this study is aimed at designing complete elements of a proposed concrete pedestrian bridge at KUST Wudil Campus main gate to reduce the rate of the accident, and to provide smooth traffic movement along the road. The design was made by a programmed spreadsheet to BS 8110-1997 2003 version. The overall length of the bridge is 14m with a width of 2.5m which is sufficient to accommodate pedestrian traffic, the height of the bridge is 5.5m, and the deck is precast in four segments of 3.5m length each, The longitudinal beams and decks are pre-stressed and precast while the remaining elements are cast in situ, The pre-stressed longitudinal beams and decks are designed as class 3 post-tensioned members, however, there are two 800 x 450 mm longitudinal beams which are themselves supported by three 700 x 500mm cross girders. Taking a segmental approach to the design proved to be more demanding than foreseen initially.*

Keywords: **Pedestrian Bridge, Design, prestressed beam, prestressed deck, spreadsheet, Bridge Design.**

1. INTRODUCTION

General design of bridge structure should be in accordance with requirements established by the owner, adapted to the geometric conditions of the site, and by the structural provisions of the applicable codes and specifications. (ACI-ASCE Committee 343, 1995). The geometry of the superstructure (beams and decks) is dictated by the specified deck width and the required clearance below the pedestrian bridge. These requirements are in turn directly related to the type of traffic passing under the pedestrian bridge as well as the volume of pedestrians to be carried on the bridge deck. (ACI-ASCE Committee 343, 1995), Once the overall geometry of the pedestrian bridge superstructure has been established, it should be designed to meet structural requirements. These should always include considerations of strength, serviceability, fatigue, and durability. (ACI-ASCE Committee 343, 1995). According to ACI-ASCE Committee 343 (1995), General- precast concrete, manufactured either at a plant or at the bridge site, offers many potential advantages in quality control, speed of construction, and frequent economy. The precast concrete pedestrian bridge, both short and long spans have been built in many environments from highly urbanized to rural areas.

The Research Study covers the areas of analysis and design of reinforced concrete bridge deck, columns, foundation as well as those of pre-stressed concrete beams. The design is in accordance to BS8110.

1.1 Need for The Research

Gaya road is a two-lane single carriageway on which motorists usually travel at high speeds. A complete absence of any facility (e.g., zebra markings or pedestrian bridge) at the university gate for safe crossing of students poses danger to their lives. It is also a problem to the motorists in the sense that they have to slow down their vehicles or even stop when there is a high volume of the pedestrian crossing. Moreover, this problem also reduces the efficiency of the expressway and thus, results in a low level of service.

1.2 Significant of the Research

The design would provide the information needed for the construction of the pedestrian bridge, this would be available for the University and Wudil community in general for reference when the need to construct the pedestrian bridge arises, the pedestrian bridge would also allow motorists to have a smooth through flow in the busy road, especially at the school main gate, this would prevent possible future accidents and fatalities. The findings will also help individuals having similar cases across the globe to adopt the design and implement it for general use with modification at the foundation level where the ground condition is not similar to those considered in this work.

2. ANALYSIS AND DESIGN DATA

2.1 Relevant Codes

The code required for the analysis and design of this pedestrian bridge are B.S.8110, AASHTO, and the B.S. 8110 deals mainly with the design of reinforced concrete structures and is the basis for all the reinforced concrete part of this design.

2.2 Elements of the Pedestrian Bridge

A typical bridge has the following essential element;

- Deck slab
- Primary Beam
- Secondary Beam
- Piers
- Footing
- Foundation

The design is done by using a programmed spreadsheet to BS 8110, the spreadsheet performed post-tensioned design for the Prestressed members and reinforced concrete design for the remaining members, the design parameters were inserted into the spreadsheet for the analysis and design to obtain the output, however, Some manual calculations were also involved as the software does not have the capacity to do all the design.

2.3 Proposed Drawings

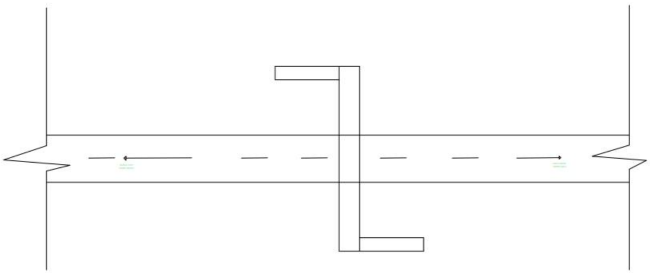


Fig 1. Site layout

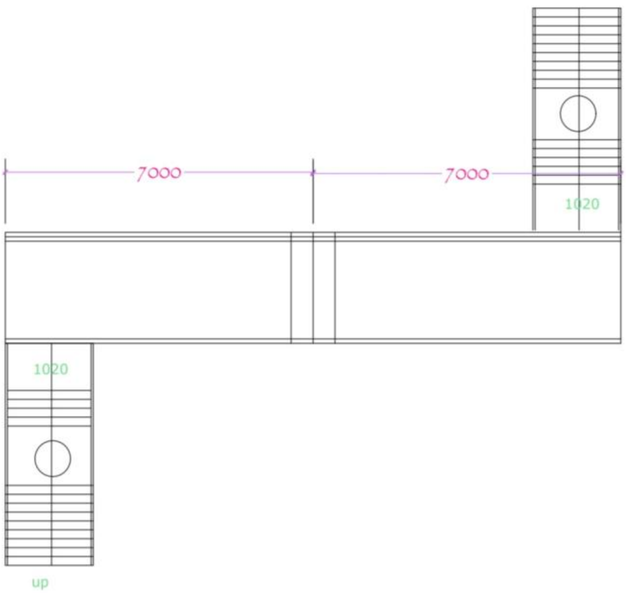


Fig 2. Plan

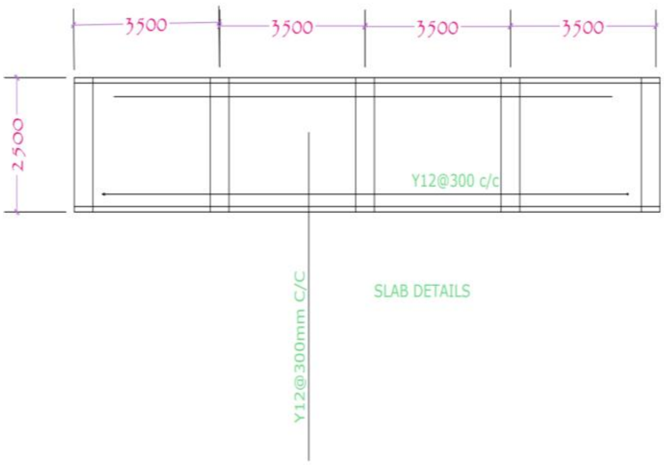


Fig 3. Slab Details

Fig 4. Stair details

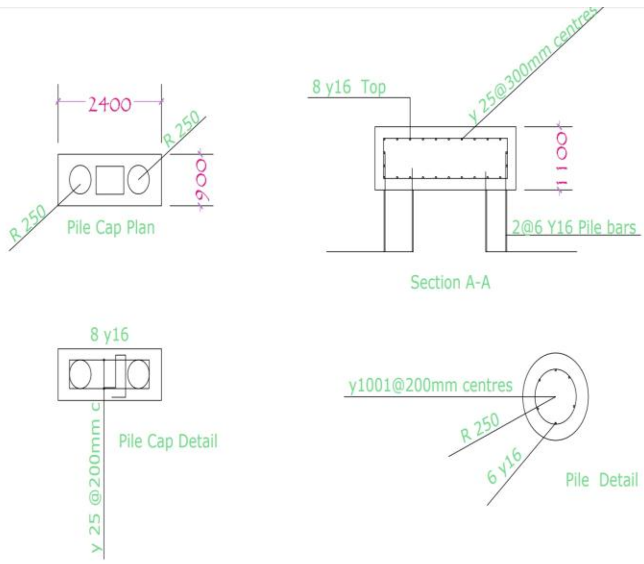


Fig 5. Pile and Pile cap details

2.4 Materials

Concrete; Characteristic strength of concrete, f_{cu}=50N/mm^2 at 28 days, γ_m=1.5. The value of f_{cu} was chosen because it satisfies the condition stated in clause 4.1.8.1 of BS 8110. The code specifies minimum f_{cu} for pre-tension and post-tension concrete as 40N/mm^2 and 35N/mm^2 respectively. It

also meets the requirement stated by Caprani (2006/7) and Raju (2007).
Cement content = 450kg/m^3. The cement content was determined in accordance with Table 3.3 of BS 8110- 1997. The code requires a minimum value of 400kg/m^3 for grade 50 concrete.
Rebar; Characteristic strength of reinforcement bars, f_y= 460N/mm^2
Strands; Tensile strength of the strands, f_{pu}= 1860N /mm^2. The value of f_{pu} was selected from the table of engineering properties of available strands as given by Caprani (2006/7) in accordance with BS 5896:1980.

2.5 Prestressing Options

Stressing Ends: The members will be jacked from both ends
Jacking Force/Strength = 0.7. This value given is used to make sure that the tensile strength of the strands is not encroached. It means that the jacking force will be limited to 0.7 of the tensile strength. This will allow the strands to yield since yield strength is always less than tensile strength as given by Caprani (2006/7).
Pre-stressed Member: BS 8110 class 3 members.
Pre-stress system: Un-bonded
Pre-stress losses: 30%
This occurs when there is no bond between the prestressing tendon and concrete, it is called an un-bonded tendon. When the grout is not applied after post-tensioning, the tendon is an unbonded tendon. The Pre-stressing Force is transferred to the concrete through the anchorage only. (Hemant, 2008).

Limiting Crack Width= 0.2mm: This is the maximum value permitted by clause 4.1.3 of BS 8110-1997.

2.6 Deck

The deck will be pre-cast with a width of 2.5m and a height of 0.175m. It will be in four segments of 3.5m each. As shown in figure 3.1, the deck is supported by two 800 x 450mm beams which are themselves supported by cross girders.

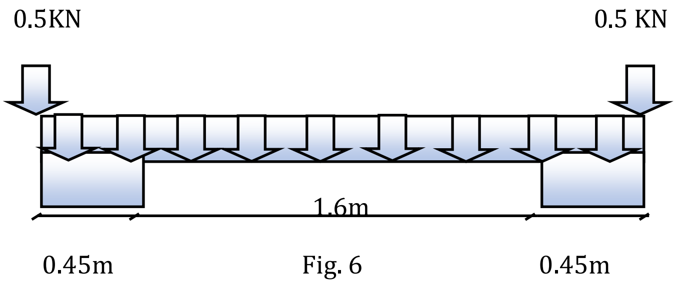


Fig. 6

Design length = clear span + bearing = 1.6 + 0.45 = 2.05m Design length is usually the effective span which is the distance between the centers of supports.

Loading on slab
Dead Load; Slab self-weight= 0.175 x24 = 4.20 KN/m^2
Weight of baluster on either side = 0.5 KN/m. This value is assumed depending on the material to be used, it is an acceptable practice to do so according to Iles, (2013).

Total dead load (udl) = 4.20 KN/m^2

Total Point Load (dead) = 0.5+ 0.5 = 1.0 KN

Live Load; Pedestrian Traffic= 4 KN/m^2. In accordance with BS 5400-2: 2006.

Design Load= 1.4 x 4.2 x 1.6 x 4.0 = 12.28 KN/m^2

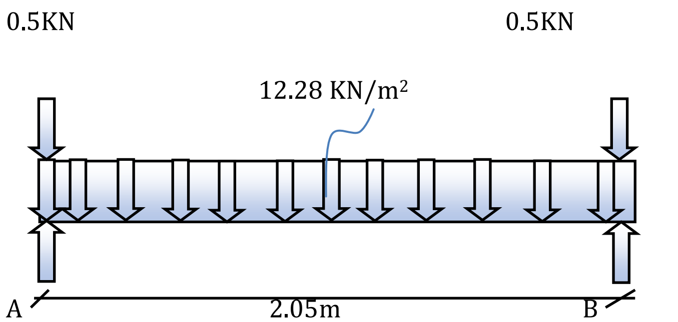


Fig.7

By symmetry $R_A = R_B$ = ½ (wl + P) = 1/2 (10.68x 2.05 + 1) = 11.45 KN/m

2.7 Staircase

Flights
Tread= 250mm

Riser= 170mmSlope factor= $(T^2 + R^2)/T = (250^2+170^2)/250$ = 1.21.

The two flights have the same number of treads.

No of treads= 19

Width of half landing= 1.5m

So, Length L= 19 x 0.25 + 0.5 x 1.5 = 5.5m.

Minimum depth = L/ (Basic span ratio x M. F.)

Where Basic span ratio = 20 from table 3.9 of BS 8110-1: 1997. (Simply supported)

Assuming a modification factor of 1.7

Minimum depth = 5500/ (20 x 1.7) = 161.76

Minimum h= d_{min} + cover + radius of bar

Using Y12 bars and a cover of 25mm

h_{min} = 161.76 + 25+ 6 = 192.76mm, Take h= 200mm

Dead Load= (24 x 0.2 + 0.5 x 24 x 0.17) x 1.21 x 1.4 =11.59 KN/m^2

Live Load = 1.6 x 4.0 = 6.4 KN/m^2
Total Load = 11.59 + 6.4 = 18 KN/m^2

Intermediate Landing
The landing has the same thickness as the waist that is 200mm.
Length of landing = 1.5m
Dead Load = 0.17 x 24 x 1.5 = 8.67 KN/m^2

Live Load = 1.6 x 4.0 = 6.4 KN/m^2

Load from fight 1= wl/2 = 18 x 5.5/2 = 49.5 KN/m^2

Load from fight 2= wl/2 = 18 x 5.5/2 = 49.5 KN/m^2

Total Load = 8.67 + 6.4 + 49.5 + 49.5 = 114.07 KN/m^2

2.8 Longitudinal Beam

Since the width of the two sides of the carriageway is the same, only the beam of one side is designed. The width of the carriageway was measured with a tape.
Length of the beam = width of carriage way + width of drainage + extra spacing
Width of carriage way = 11.5m, Width of drainage = 1.5m, plus 1m spacing
Length of the beam = 11.5+ 1.5 + 1 = 14m

Loading on the beam; Since the deck is simply supported, the reaction of the beam due to the deck loading is the total load acting on the beam which has been calculated as 12.28KN/m. According to Mosey and Bungey (1990) for post-tensioned members, h= span/25 + 0.5m if span is less than 30m.
So, h_{min}= 14000/25 + 100 = 660m, Try h of 800mm.
Beam self-weight (800 x 450mm beam) = 0.8 x 0.45 x 24 x 1.4 = 12.10KN/m

Load from flight 2 = wl/2 = 18 x 5.5/2 = 49.5 KN. The flight load acts in the one extreme end of the beam.
Weight of baluster = 0.5 KN
Therefore; Total loading on the beam (udl) = 12.28 + 12.10 = 24.38 KN/m

Total Point Load = 49.5 + 0.5 = 50 KN

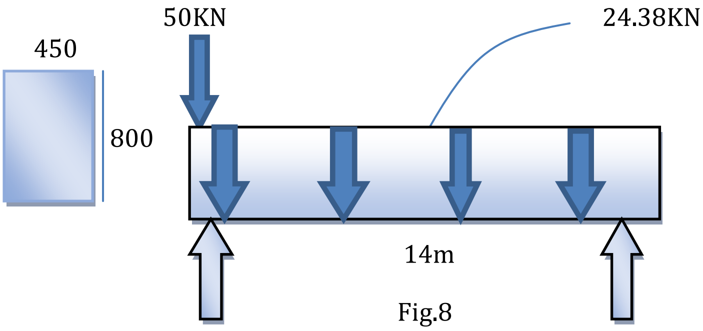


Fig.8

2.9 Transverse Beam

The beam has a dimension of 700 x 500 mm and 1.2 m cantilevered end in both sides.
Self-weight of the beam = 0.7 x 0.5 x 0.7 x 1.4 = 11.76 KN/m^2

Central Transverse Beam
Load from longitudinal beams = 24.38 x 14/2 + 24.38 x 14/2 = 352.66 KN.

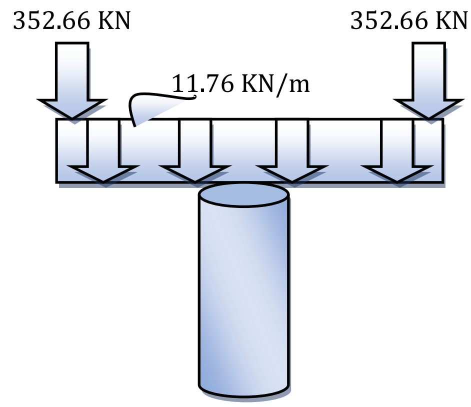


Fig. 9

Maximum Moment = -(Pl + wl/2) = -(352.66 x 1.2 + 11.76 x 1.2/2) = -430.25 KNm
Maximum shear force = P + wl = 352.66 + 11.76 x 1.2 = 366.77 KN.

Edge Transverse Beam
Load from longitudinal beams 24.38 x 14/2 =170.66 KN
Load from Flight 2 on the right-side cantilever (including weight of rails) = wl/2 = 18 x 5.5/2 = 50 KN.

Total Load on right side cantilever = 170.66 + 50 = 220.66 KN.
Maximum Moment = -(Pl + wl/2) = - (220.66 x 1.2 + 11.76 x 1.2/2) = -271.85 KN.
The design will be based on central transverse beam moment since it is the most critical.

2.10 Column

Central Column
Axial load on the central column = Load on central transverse beam + self-weight of the beam.
N = 352.66 x 2 + 11.76 x 2.5 = 734.72 KN

The height of the column is 5m.
The column is axially loaded because of the symmetry of span and loading.

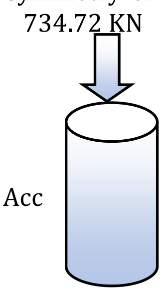


Fig.10

Minimum Asc/Ac = 0.4%

Maximum Asc/Ac = 6%

Take Asc/Ac = 1%N= $0.4f_{cu}$Acc + $0.8f_y$ x 0.01x Acc

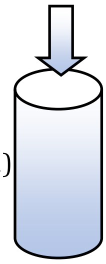
So, Acc = N/ ($0.4f_{cu}$ + $0.8f_y$ x 0.01) = 734.72 x 10^3/ (0.4 X 50 + 0.8 x 460 x 0.01) = 31,027.03mm^2.

Using a circular column, try a column with a diameter of say 400mm. (A = 125,663.71mm^2)
Circular column can be designed as equivalent rectangular column. Using 400 x 400 square columns

Edge Column

Axial load on the central column = Load on edge transverse beam + self-weight of the beam. = 220.66 + 170.66 + 11.76 x 2.5 = 420.72 KN

420.72 KN



N= $0.4f_{cu}$Acc + $0.8f_y$ x 0.01x Acc

So, Acc = N/ ($0.4f_{cu}$ + $0.8f_y$ x 0.01)

= 420.72 x 10^3/ (0.4 X 50 + 0.8 x 460 x 0.01)

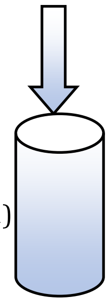
= 17766.89mm^2.

Fig. 11

It is obvious that the central column is the most critical; therefore, the design will be based on it.

Half Landing Column
Axial load on the central column = Load on landing + self-weight of the landing. = 114.07 KN

114.07 KN



The height of the column = 2.5 m

N= $0.4f_{cu}$Acc + $0.8f_y$ x 0.01x Acc

So, Acc = N/ ($0.4f_{cu}$ + $0.8f_y$ x 0.01)

= 114.07 x 10^3/ (0.4 x 50 + 0.8 x 460 x 0.01)

= 4817.15mm^2.

Fig.12

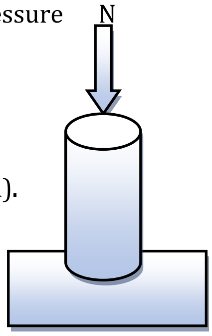
Try a circular column of diameter 300mm. The column can be designed as 300 x 300 square columns.

2.11 Foundation

Central Column Foundation Analysis
Total load on the foundation, Axial load on the column + self-weight of the column
N = 734.72 + (1.4 x 24 x 0.126 x 5) = 755.83 KN.

Base Area = N serviceability / Net Pressure

N



N serviceability = 755.83/ 1.46

= 517.69 KN.

Net Pressure = 130 KN/ m^2 (Assumed).

Base Area = 517.69 / 130 = 3.98m^2

Try 2.5 x 2.5 x 0.5m base (A= 6.25m^2)

Fig.13

Edge Column Foundation

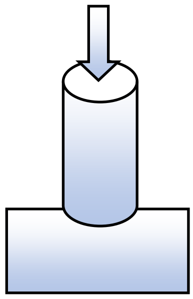
Total load on the foundation, Axial load on the column + self-weight of the column

N = 420.72 + (1.4 x 24 x 0.126 x 5) = 441.89 KN.

Base Area = N serviceability / Net Pressure

N serviceability = 441.89/ 1.46 = 302.66 KN.

N



Net Pressure = 130 KN/ m^2

Base Area = 302.66 / 130 = 2.33m^2

Try 2.0 x 2.0 x 0.45 m base (A= 4m^2).

Fig.14

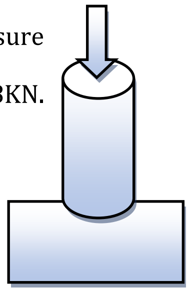
Intermediate Landing Foundation

Total load on the foundation, Axial load on the column + self-weight of the column

N = 114.07 + (1.4 x 24 x 0.126 x 2.5)

N= 124.65KN.

N



Base Area = N serviceability / Net Pressure

N serviceability = 124.65 / 1.46 = 85.38KN.

Net Pressure = 130 KN/ m^2

Base Area = 85.38 / 130 = 0.66m^2

Try 1.0 x 1.0 x 0.4m base (A= 1m^2).

Fig.15

3. RESULT AND DISCUSSION

3.1 Design Summary

Note: The Summary below provide the final result summary of the design. Detailed design cannot be provided due to the Huge number of pages.

Table 1. Deck Details

Reinforcement Details	Main Reinforcement	Distribution Reinforcement	Shear Links
	12Y16	12Y8	Not Needed
Percentage of Steel	0.551%	0.138%	

Table 2. Staircase Details

Reinforcement Details	Main Reinforcement	Distribution Reinforcement
Flights 1 And 2	Y16 – 260 c/c	Y12 – 425 c/c
Half Landing	Y12- 390 c/c	Y12 – 500 c/c

Table 3. Longitudinal Beam Details

Reinforcement Details	Span Reinforcement	Support Reinforcement	Shear Links
	5Y20	5Y12	Y8- 200 c/c
Percentage of Steel	0.436%	0.157%	

Table 4. Transverse Beam Details

Reinforcement Details	Top Reinforcement	Bottom Reinforcement	Shear Links
	6Y20	3Y16	Y8- 125 c/c

Table 5. Central Column Details

Reinforcement Details	Compression Reinforcement	Links
	4Y20	Y8 – 225 c/c

Table 6. Edge Column Details

Reinforcement Details	Compression Reinforcement	Links
	4Y20	Y8- 225 c/c

Table 7. Half Landing Column Details

Reinforcement Details	Compression Steel	Links
	416	Y6- 175 c/c

Table 8. Foundation Details

Reinforcement Details	Main Reinforcement	Distribution Reinforcement
Central Foundation	15Y12- 175 c/c	15Y12- 175 c/c
Edge Foundation	11Y12- 200 c/c	11Y12- 200 c/c
Landing Foundation	5Y12-225 c/c	5Y12-225 c/c

3.2 Discussion of Results

The spacing of distribution reinforcement of the two flights was determined by the software as 377mm, this, however, exceeded the maximum allowable spacing and as such, it should be limited to 300mm, for the same reason, the spacing between main and distribution reinforcement should also be limited to 300mm. The software also gave the number of compression reinforcement as 4Y20 for central and 3Y20 edge columns, and 3Y12 for the landing column, however, Since the columns are circular, a minimum number of 6 bars is required, therefore, 5 additional bars should be added. The number of bars for the central and edge column would be 6Y20 and 6Y13 for the half landing column.

4. CONCLUSIONS

The design was produced in adherence to the provision of relevant codes of practice and with regards to previous works and great ideas of prominent designers in the civil engineering field. The components designed according to B.S. 8110 includes the stair, slab, beam and the foundation to distribute the load to bearing capacity of the soil. The option of the reinforced concrete section for the pedestrian bridge was aimed at the maximization of materials, reduction in the dead weight of the bridge, economy, and safety throughout the service life of the bridge.

This study can, therefore, be used for the construction of pedestrian bridges anywhere in the world with modification at the foundation level where the ground conditions are not similar to those considered in this work.

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