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Final Paper on Study and Design of Footbridge to connect the first floor of Civil and Mechanical Engineering Departments of JCOET Yavatmal

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Abstract - *In an effort to enhance accessibility and promote collaboration between academic departments, this paper aims to design a functional footbridge to connect the first floors of the Civil Engineering Department and Mechanical Engineering Department at JCOET (Jagadambha College of Engineering and Technology), Yavatmal. This paper, therefore, primarily focuses on the comprehensive design of an RCC footbridge. The procedure first consists of a thorough site survey. It then focuses on designing the bridge slab and beams using limit state method of IS 456:2000.The rate analysis of the complete project is then generated. We developed a 3D model of the proposed footbridge using AutoCAD as well as a physical prospective model.*

***Keywords*: Footbridge, Civil Engineering Department, Mechanical Engineering Department, JCOET, limit state method, rate analysis, modelling.**

1. INTRODUCTION

A footbridge, often referred to as a pedestrian bridge, serves as a dedicated passageway exclusively designed for pedestrians. These constructions not only fulfil a utilitarian purpose but also contribute to the visual aesthetics of an environment, serving as ornamental elements that establish visual connections between distinct areas or mark transitions. While the traditional notion of a bridge pertains to a structure that links two points at an elevated height, a footbridge can also operate as a ground-level structure, such as a boardwalk, facilitating pedestrian movement across areas characterized by damp, delicate, or marshy terrain. Bridges have undergone a transformative evolution throughout history, ranging from rudimentary stepping stones or fallen trees to intricate steel structures. Certain footbridges embody both functionality and artistic magnificence.

In the case of JCOET, Yavatmal, there was a need to join the two buildings of Civil and Mechanical Departments, providing a safe walking way during bad weather conditions while also improving the campus aesthetics. The construction site survey was carried out manually, employing measuring tape for data collection. This paper predominantly centers on the extensive design of an RCC footbridge manually and then creating a 3D model using AutoCAD. A physical prospective model is also developed. The design aims to connect the first floors of these two buildings effectively.

1.1 Need of Footbridge

The footbridge is needed to connect the first floors of Civil and Mechanical Engineering Departments for the purpose of convenient access during monsoon when the land becomes marshy. Also, the faculty members and students have to go around a longer path while walking from the Civil Department to the Mechanical Department and vice versa.

JCOET, Yavatmal offers five engineering branches and each branch has its own seminar hall in the college. Among the five seminal halls, Civil Department's Seminar Hall is called Sir Visvesvaraya Seminar Hall. It is the largest seminar hall among the five. Therefore, whenever the college authorities need to address all college students together, Sir Visvesvaraya Seminar Hall is used by them to assemble all the college students. Therefore, the proposed footbridge is very advantageous as it will help the students and staff from the Mechanical Department and Electronics Department as this department is also located in the same building as the Mechanical Department, to directly access the Civil Department. It is also saves time due to such direct access.

2. METHODOLOGY

2.1 Site Survey

Construction Surveying was the type of site surveying method followed for surveying the site. The survey was done using tape. It then was plotted using AutoCAD.

Fig -1: Civil Department Building

Fig -2: Mechanical Department Building

The following specifications were obtained as a result of the conducted survey:
1) Clear Span of the proposed footbridge = 3.70 meter
2) Length of span between Civil and Mechanical Engineering Department Building i.e. Length of Bridge Slab = 9.80 m
3) Height of First Floor = 4.10 m

2.2 Design of Footbridge

Upon reviewing different types of footbridges, we came to the conclusion that RCC Slab Footbridge design is suitable for our construction as it can be successfully implemented for shorter spans with less thickness and is cost effective. Detailed designs for the footbridge were developed. The design of the bridge slab and beam were developed using limit state method according to the guideline specified by IS 456:2000.

2.3 Rate Analysis

Rate Analysis of footbridge was generated to determine the total cost of the project.

2.4 Model rendering using Software Approach

We made use of AutoCAD software to build and render the 3D model of the proposed footbridge.

2.5 Prospective Model

The information gathered from the preceding stages was utilized to formulate a potential prototype for the footbridge.

3. DESIGN OF FOOTBRIDGE

3.1 Design of Bridge Slab

As length of the slab is more than two times the width, it is a one-way slab.
The shorter span will bear the weight or load that needs to be supported.
Considering a 1 meter wide strip of the slab being parallel to its shorter span.
Let us assume,
Depth'd' = 100 mm
Overall depth 'D' = 100 +15 +5
= 120 mm
Dead load of slab = 0.12 x 1 x 25
= 3 kN/m
Superimposed load for pedestrians = 5 x 1
= 5.00 kN/m
Total load = 8 kN/m
Factored load, with load factor 1.5 = 1.5 x 8
= 12 kN/m
Steel reinforcement 10 mm diameter with clear cover of 15 mm
Support width = 350 mm
Effective depth d = 120-15-5
= 100 mm
Effective span of slab should be lesser of the following
(i) Center to center distance between supports
= 3.70 + 0.35
= 4.05 mm
(ii) Clear span + effective depth = 3.70 + 0.10
= 3.80 m
So, effective span will be 4.05 m
Maximum Bending Moment at center of shorter span $= \frac{wul^2}{8}$

Now, Maximum bending moment = $\frac{12*4.05^2}{8}$
= 24.60 kNm

Depth of slab:
B.M. = 0.138 $fckbd^2$

$$d = \sqrt{\frac{\text{B.M.}}{0.138 \text{ fck b}}}$$

$$= \sqrt{\frac{24.60*10^6}{0.138*25*1000}}$$

= 84.44 mm
Adopt effective depth 'd' = 100 mm
Overall depth 'D' = effective depth + effective cover
= 100 + 15 + 5
= 120 mm

Area of tension steel is given by

$M = 0.87\ fyAst(d - \frac{fy.Ast}{fck\ b})$

$24.60 \times 10^6 = 0.87 \times 415 \times Ast\ (100 - \frac{415\ X\ Ast}{25\ X\ 100})$

$Ast = 784.28\ mm^2$

Use 10 mm dia bars

No. of bars required $= \frac{Ast}{Area\ of\ one\ 10\ mm\ Bar}$

$= \frac{784.28}{\frac{\pi}{4} X\ 10^2}$

$= 9.98 \approx 10$ Nos

Spacing of bar $= \frac{1\ m\ wide\ strip\ of\ slab}{No\ of\ bars}$

= 1000/10

= 100 mm c/c

Spacing should be lesser of:

(a) 100 mm (as per design calculations)

(a) 3d = 3x100 = 300 mm

(b) 300 mm

Provide 10 mm bars @ 100 mm c/c,

Area=

$= \frac{1000}{100}\ X\ \frac{\pi}{4}\ X\ 10^2$

$= 785.39 > 784.28\ mm^2$

Hence, OK

Temperature reinforcement 0.12% of the gross concrete area will be provided in the longitudinal direction.

= 0.0012 x 1000 x 120

= 144 mm2

Use 8 mm bars, Spacing $= \frac{\frac{\pi}{4} X\ 8^2}{144}\ X\ 1000$

= 349.06 mm

Spacing should be lesser of :

(a) 300 mm (as per design calculations)

(b) 450 mm or

(c) 5d i.e., 5 x 100 = 500 mm

So, provide 8 mm bars @ 300 mm c/c, giving area of steel

$= \frac{1000}{300}\ X\ \frac{\pi}{4}\ X\ 8^2$

$= 167.55\ mm^2 > 144\ mm^2$

Hence, OK

<u>Check for Shear:</u>

We know that at supports 50% of main reinforcement is available, so calculate

% tension steel at support $= \frac{100\ ASt}{bd}$

$= \frac{100\ X\ 784.28}{1000\ X\ 100}$

= 0.78 %

Now, from table 19 of IS 456: 2000,

For 0.75 % Steel, M25 grade Concrete

$\tau c = 0.57\ N/mm^2$

For 1.00 % Steel, M25 grade Concrete

$\tau c = 0.64\ N/mm^2$

So, by interpolation,

τc for 0.78 % steel = $0.58\ N/mm^2$

For 120 mm thick solid slab, k = 1.30 (from table 20 of IS 456: 2000)

$\tau' c = k\tau c = 1.30 \times 0.58$

$= 0.75\ N/mm^2$

Nominal shear stress $\tau v = \frac{Vu}{bd}$

Where Vu is maximum shear force, i.e., at support $= \frac{Wulc}{2}$

$= \frac{12\ X\ 3.7}{2}$

= 22.2 KN

Now, $\tau v = \frac{22.2\ X\ 1000}{1000\ X\ 100}$

$= 0.22\ N/mm^2 < \tau c$

Hence, OK

The slab is safe in shear

<u>Check for development length:</u>

From clause 26.2.3.3 of IS 456: 2000,

$\frac{M}{V} + Lo > Ld$

$$\frac{24.60\ X\ 10^6}{22200} + 0 > \frac{\emptyset\ (0.87\ fy)}{4\ \tau bd}$$

$$= \frac{24.60\ X\ 10^6}{22200} + 0 > \frac{10\ X\ 0.87\ X\ 415}{4\ X\ 1.4\ X\ 2}$$

1108.10 mm > 322.36 mm

Hence, safe in development length.

The code requires that steel reinforcing bars must be carried in to supports by at least $Ld/3$

= 40x10/3

= 133.33 mm or 135 mm (say)

<u>Check for deflection:</u>

% of tension reinforcement at mid span

$pt = \frac{100\ Ast}{bd}$

$= \frac{100\ X\ 784.28}{1000\ X\ 100}$

= 0.78%

Refer to table showing the values of γ, for pt = 0.78% at a service stress of 240 Mpa in Fe 415 grade steel

By interpolation, value of γ = 1.06

So, we know

$\frac{L}{d} \leq \alpha\beta\gamma\delta\lambda$

Here α = 20, for simply supported slab up to 10 m span

So β = 1, γ = 1.06, δ = 1 and λ = 1

So, allowable

$\frac{L}{d} = 20 \times 1 \times 1.06 \times 1 \times 1$

= 21.2

Actual $\frac{L}{d}$ = 3800 / 100

= 38 > 21.2 (NG)

The Slab fails in deflection.

Therefore, the depth of the slab needs to be increased.

Let us increase the effective depth of slab to 150 mm and overall depth to 170 mm.

Calculate Area of tension steel, when d = 140 mm

$M = 0.87\ fyAs(d - \frac{fy.Ast}{fck\ b})$

$24.60\ X\ 10^6 = 0.87 \times 415 \times As(150 - \frac{415 \times Ast}{25 \times 1000})$

$Ast = 479.70\ mm^2$

$784.28\ mm^2 > 479.70\ mm^2$

Hence, OK

Calculate the spacing of 10 mm bars

Spacing = $\frac{\frac{\pi}{4} X\ 10^2}{479.70}\ X\ 1000$

= 163.73 mm

Provide 10 mm bar @ 150 mm c/c

Temperature reinforcement = 0.12% of gross concrete area

= 0.0012 x 1000 x 170

= 204 mm^2

Provide 8 mm bars @ 200 mm c/c, giving total area

= $\frac{1000}{200} X\ \frac{\pi}{4}\ X\ 8^2$

= 251.32 mm^2

251.32 mm^2> 204 mm^2

Hence, OK

<u>Check for Shear:</u>

% tension steel at support = $\frac{100\ Ast}{bd}$

= $\frac{100\ X\ 479.70}{1000\ X\ 150}$

= 0.31 %

For 0.25% Steel, M25 grade Concrete

τc = 0.36 N/mm^2

For 0.50% Steel, M25 grade Concrete

τc = 0.49 N/mm^2

So, by interpolation,

τc for 0.31% steel = 0.39 N/mm^2

For 170 mm thick solid slab, k = 1.26 (by interpolation from table 20 of IS 456: 2000)

$\tau' c = k\tau c$ = 1.26 x 0.39

= 0.49 N/mm^2

Now,

$\tau v = \frac{22.2\ X\ 1000}{1000\ X\ 150}$

= 0.15 N/mm^2 $<\tau' c$

Hence, OK

The slab is safe in shear

<u>Check for deflection:</u>

% of tension reinforcement at mid span

$pt = \frac{100\ Ast}{bd}$

$= \frac{100\ X\ 78.43\ X\ \frac{1000}{150}}{1000\ X\ 150}$

= 0.35 %

Refer to table showing the values of γ, for pt = 0.35% at a service stress of 240 Mpa in Fe415 grade steel

γ = 1.37

So, we know

$\frac{L}{d} \leq \alpha\beta\gamma\delta\lambda$

Here α = 20, for SS Span So, β = 1, γ = 1.37, δ = 1 (for no compression reinforcement) and λ = 1. So, allowable

$\frac{L}{d}$= 20 × 1 × 1.37 × 1 × 1

= 267.4

Actual $\frac{L}{d} = \frac{3800}{150}$

= 25.33

25.33 < 27.4

Hence OK. The slab is now safe in deflection

3.2 Design of Beam

Support width= 350 mm

Clear span = 3.7 m = 3700 mm

b = 350 mm

Live Load = 5 KN/m^2 (as pedestrian load on slab is 5 KN/m^2)

fck = 25 N/mm^2

fy= 415 N/mm^2

From page 37 of IS 456:2000,

$\frac{L}{d}$ = 10

d = $\frac{L}{10}$

= $\frac{3700}{10}$

= 370 mm ≈ 400 mm

d = 400 mm

Assume effective cover d' = 30 mm

D = d + d'

= 400 +30

= 430 mm

Self weight of beam = b x D x ρ

= 0.35 x 0.43 x 25

= 3.76 KN/m

W1= 5 KN/m

W=W1+WD

= 5 + 3.76

= 8.76 KN/m

Ultimate Load, Wu = 1.5 x 8.76

= 13.14 KN/m

Clear span = 3700 mm

Calculation of effective span

1. Effective span = clear span + effective depth

   = 3.7 + 0.40

   = 4.1 m

2. Effective span = clear span + c/c distance between supports

   = 3.7 + $\frac{0.35}{2}$ + $\frac{0.35}{2}$

   = 4.05 m

Select whichever is less

SO, l_{eff}= 4.05 m

Design B.M = $\frac{Wul^2}{8}$

= $\frac{13.14\ X\ 4.05^2}{8}$

= 26.94 KN-m

Mu = 0.138 fck bd² (For Fe415)

$d^2 = \frac{Mu}{0.138\ fck\ b}$

d = $\sqrt{\frac{26.94\ X\ 10^6}{0.138\ X\ 25\ X\ 350}}$

d = 149.36 mm

This is the required depth.

$d_{provided}$ (400 mm) >$d_{required}$ (149.36mm)

Hence, ok

Mulim = 0.138 fck bd^2
= 0.138 x 25 x 350 x 400^2
= 193.2 KN-m
Mulim> Mu

So, the beam is designed as a singly reinforced beam.

Calculation of Ast

Mulim = 0.87 fy Ast d $(1-\frac{fy\ Ast}{fck\ bd})$

193.2×10^6= 0.87 415 x Ast x 400$(1-\frac{415\ X\ Ast}{25\ X\ 350\ X\ 400})$

Ast = 1667.43 mm^2

Use 20 mm dia bars

No. of bars = $\frac{1667.43}{\frac{\pi}{4}X\ 20^2}$
= 6 bars

Spacing = $\frac{\frac{\pi}{4}X\ 20^2}{1667.43}$ x 1000
= 188.41 mm

Provide 6- 20 mm dia bars @ 180 mm c/c

Actual Ast = 6 x $\frac{\pi}{4}$ x 20^2
= 1884.95 mm^2

Min Ast = $\frac{0.85\ bd}{fy}$
= $\frac{0.85\ X\ 350\ X\ 400}{415}$
= 286.74 mm

As Actual Ast> Min Ast.

Hence, Ok

<u>Shear R/F:</u>

Factored S.F = $\frac{Wul}{2}$
= $\frac{13.14\ X\ 4.05}{2}$
= 26.60 KN

From page 72 of IS 456:2000,

Nominal shear stress, τ_v

$\tau_v = \frac{Vu}{bd}$
= $\frac{25.60\ X\ 10^3}{350\ X\ 400}$
= 0.19 N/mm^2

% of tension R/F

P = $\frac{Ast}{bd}$ x 100
= $\frac{1884.95}{350\ X\ 400}$ x 100
= 1.34%

Design shear strength of concrete, τ_c

From Table 19 of IS 4562:2000,

For p = 1.00%, τ_c = 0.64 N/mm^2

For p = 1.25%, τ_c = 0.70 N/mm^2

By Interpolation,

τ_c= 0.68%

As, $\tau_v<\tau_c$

No Need to provide shear Reinforcement

<u>Check for deflection:</u>

From page 38 of IS 456:2000,

% of steel = 1.19%

fs = 0.58 fy x $\frac{Ast\ required}{Ast\ provided}$
= 0.58 x 415 x $\frac{1667.43}{1884.95}$
= 212.92 N/mm^2

From fig 4 of IS 456:2000,

M.F = 1.1

$(\frac{l}{d})_{max}$= 20 K
= 20 x 1.1
= 22

$(\frac{l}{d})_{prov}$= $\frac{4050}{400}$
= 10.12

$(\frac{l}{d})_{max}>(\frac{l}{d})_{prov}$

Hence, safe in deflection.

4. RATE ANALYSIS

4.1 Rate Analysis of Bridge Slab

S.No	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
A.	**MATERIAL**				
1	CEMENT	BAG	45	370/bag	17020 RS
2	SAND	CUM	1.58	2133/cum	3370.14 RS
3	AGGREGATE	CUM	3.175	1022/cum	3244.85 RS
4	STEEL	KG	494.55	55/kg	27200.25 RS
5	BINDING WIRE	KG	4.94	65/kg	321.1 RS
6	SHUTTERING	SQM	44.12	30/sqm	1323.6 RS
B.	**LABOUR**				
	for laying reinforced concrete				
1	BELDARS	DAY	6.73	400/day	2692 RS
2	MAZDOOR	DAY	6.73	300/day	2019 RS
3	BHISHTI	DAY	3.36	500/day	1680 RS
4	MASON	DAY	1.12	650/day	728 RS
	for centering and shuttering				
1	BELDARS	DAY	14.09	400/day	5636 RS
2	CARPENTERS	DAY	14.09	700/day	9863 RS
	reinforcement work for RCC				
1	BLACKSMITH	DAY	4.94	700/day	3458 RS
2	BELDARS	DAY	4.94	400/day	1976 RS
				TOTAL	80531.94 RS

Table -1: Rate Analysis of Bridge Slab

Add 1.5% water charges of total cost = $\frac{1.5}{100}$ X 80531.94
= 1207.97 RS

Add 10% contractor charges =$\frac{10}{100}$ X 80531.94
= 8053.19 RS

Grand Total = 80531.94 + 1207.97 + 8053.19
= 89793 RS

4.2 Rate Analysis of Beam

S.No	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
A.	**MATERIAL**				
1	CEMENT	BAG	6	370/bag	2220 RS
2	SAND	CUM	0.2	2133/cum	426.6 RS
3	AGGREGATE	CUM	0.41	1022/cum	419.02 RS
4	STEEL	KG	128.74	55/kg	7080.7
5	BINDING WIRE	KG	1.28	65/kg	83.2
6	SHUTTERING	SQM	9.7	30/sqm	291 RS
B.	**LABOUR**				
	for laying reinforced concrete				
1	BELDARS	DAY	0.86	400/day	344
2	MAZDOOR	DAY	0.86	300/day	258
3	BHISHTI	DAY	0.43	500/day	215
4	MASON	DAY	0.14	650/day	91
	for centering and shuttering				
1	BELDARS	DAY	4.04	400/day	1616
2	CARPENTERS	DAY	4.04	700/day	2828
	reinforcement work for RCC				
1	BLACKSMITH	DAY	1.28	700/day	896
2	BELDARS	DAY	1.28	400/day	512
				TOTAL	17280.52 RS

Table -2: Rate Analysis of Beam

Add 1.5% water charges of total cost = $\frac{1.5}{100}$ X 17280.52 RS
= 259.20 RS

Add 10% contractor charges = $\frac{10}{100}$ X 17280.52
= 1728.05 RS

Grand Total = 17280.52 + 259.20 + 1728.05
= 19267.77 RS

Cost for 2 beams = 2 x 19267.77
= 38535.54 RS

4.3 Total Project Cost

Total Cost of Bridge Slab = 89793 RS
Total Cost of 2 Beams = 38535.54 Rs
Total Project Cost = 89793 + 38535.54
= RS **1,28,328.54**

5. RESULTS

1) After conducting the site survey, the following specifications were obtained.
   i. Clear Span of the proposed footbridge = 3.70 meter
   ii. Length of span between Civil and Mechanical Engineering Department Building i.e. Length of Bridge Slab = 9.80 m
   iii. Height of First Floor = 4.10 m

2) The design of bridge slab was developed using limit state method of IS 456:2000.
   i. As the length of the slab was twice the width, the slab was designed as a one-way slab.
   ii. The bridge slab was found to be safe in shear and safe in development length.
   iii. Initially, the slab failed in deflection. Upon increasing the depth of the slab suitably, the slab was found to be safe in deflection.

3) The design of beam was developed using limit state method of IS 456:2000.
   i. As the limiting moment was greater than the design moment, the beam was designed as a singly reinforced beam.
   ii. In the beam, as $\tau_v < \tau_c$, there was no need to provide shear reinforcement.
   iii. The beam was found safe in deflection

4) After the rate analysis, the cost were calculated as follows
   i. Total cost of Bridge Slab = 89793 RS
   ii. Total Cost of 2 Beams = 38535.54 Rs
   iii. Total Project Cost = 89793 + 38535.54 = **RS 1,28,328.54**

5) Model Rendering using AutoCAD

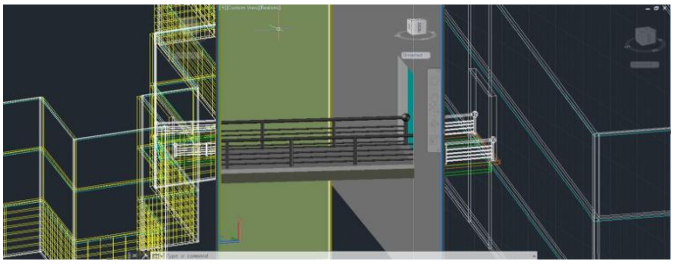

Fig -3: 3D model of proposed footbridge using AutoCAD

6) Prospective Model

Fig -4: Front view of modular representation of proposed footbridge in JCOET Campus

Fig -5: Side view of modular representation of proposed footbridge in JCOET Campus

6. CONCLUSION

The site survey furnished crucial information regarding the physical layout and dimensions of the location, guaranteeing that the design harmonized with the unique features of the site. This footbridge was designed manually taking in considerations all necessary loads and its total estimated cost is found to be 1,28,328.54 RS.

We believe that the successful completion of this project will bring significant advantages to the entire academic community, including faculty members, staff, and students. It will provide a convenient and efficient pathway connecting the Civil Building to the Mechanical Building, particularly beneficial during various events held in Sir Visvesvaraya Seminar Hall located on the ground floor of the Civil Engineering Department Building. This will eliminate the need for faculty members and students who are on the first floor of the Mechanical Building to descend to the ground level and then re-enter the Civil Building. Instead, they can seamlessly traverse from the first floor of the Mechanical Building to the first floor of the Civil Building via the proposed footbridge and then to the ground floor. Similar is the case for Mechanical Engineering Department's Seminal Hall located on the first floor of the building.

Furthermore, the footbridge will alleviate the inconvenience of navigating the campus grounds, especially during the monsoon season when the terrain becomes marshy. This will ensure a safer and more comfortable experience for everyone moving between these two important academic buildings.

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