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Defection Due to Flexural & Shear Stress

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Abstract

The bending moment and shear force are fundamental factors in determining the deflection of structural elements like beams, slabs, and girders. Bending moments generate flexural stress, which influences the bending capacity of a material, while shear forces produce shear stress, affecting the material's ability to resist deformation. These stresses are countered by the flexural strength and shear strength of the material, ensuring stability under applied loads. Among the two, flexural stress plays a dominant role, being approximately 2.58 times greater than shear stress, making it a critical factor in structural deflection analysis. Deflection, a measure of structural deformation, results from the combined effects of flexural and shear stresses. Its magnitude must remain within permissible limits outlined in design codes, such as IS 456:2000 and ACI 318, to ensure the safety, functionality, and durability of a structure. Excessive deflection can lead to serviceability issues, including cracking, excessive vibrations, and, in extreme cases, structural failure. Consequently, accurately predicting and mitigating deflection is essential in structural design and analysis. Understanding the relationship between bending moment, shear force, and their resulting stresses is vital for designing effective structural systems. Modern materials, such as high-strength concrete, fiber-reinforced polymers, and nano-enhanced composites, offer enhanced flexural and shear capacities, reducing deflection and improving performance. By incorporating these advanced materials and analytical methods, engineers can optimize the design of structural elements to achieve a balance between material efficiency and structural safety. This study highlights the importance of deflection analysis by examining the contributions of flexural and shear stresses and their relationship to material properties. It emphasizes the need for innovative solutions to meet design requirements and enhance the performance of structures under diverse loading conditions.

Keywords: Bending stress, shear stress, flexural strength, shear strength, structural deflection

INTRODUCTION

Deflection in structural elements such as beams, slabs, and girders is a critical parameter in structural design, as it directly affects the serviceability and stability of a structure. Both flexural stress and shear stress contribute to deflection, although their impacts differ significantly. Flexural stress arises due to the bending moment, which is caused by loads acting perpendicular to the longitudinal axis of a beam. Shear stress, on the other hand, results from forces acting parallel to the cross-section of the material [1-3].

For a beam subjected to a load, the combined effects of flexural and shear stresses determine the overall deflection. These deflections must be carefully compared with permissible values specified in design codes, such as IS 456:2000 or ACI 318, to ensure the structure's safety and functionality [4-6].

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RESULTS & DISCUSSION

Relationship Between Bending and Shear Stresses

The relationship between bending moment and shear force plays a pivotal role in understanding deflection. Flexural stress, induced by bending moments, has a pronounced impact on the material due to its magnitude being approximately 2.58 times greater than that of shear stress. This ratio emphasizes the necessity of prioritizing flexural strength in design considerations [7-9].

Deflection Analysis

Deflection is analyzed by combining the effects of both flexural and shear stresses. For beams, the total deflection can be expressed as:

$$\Delta_{total} = \Delta_{flexural} + \Delta_{shear}$$

Here, $\Delta_{flexural}$ is primarily influenced by the modulus of elasticity and moment of inertia of the beam section, while Δ_{shear} depends on the shear modulus and the geometry of the cross-section [10].

Permissible Deflection

Permissible deflection is determined based on the intended use and span of the structural member. Excessive deflection can lead to serviceability issues such as cracking, vibration, or even failure in extreme cases. For instance, in simply supported beams, the permissible deflection is often limited to span/250 for normal applications.

Implications for Structural Design

Designing for deflection involves ensuring that the flexural strength of the material exceeds the applied flexural stress and that the shear strength adequately resists shear stress. Materials like reinforced concrete and structural steel exhibit varying flexural and shear capacities, which must be accounted for during the design process. Incorporating high-performance materials, such as fiber-reinforced polymers or nano-enhanced concrete, can significantly improve both flexural and shear strength, reducing overall deflection.

- Deflection due to bending stress

Span of beam = 6.6 m
Load = 14300 N/m
Total load = 9.438 t

$$w = \frac{9.438}{6.6} = 1.43\ t/m$$

$$M = \frac{1.43\ x\ (6.6)^2}{8} = 7.786\ t - m$$

- *Flexural stress*: Using bending equation

$$\frac{7.786\ x\ 1000\ x\ 10\ x\ 1000}{\frac{1}{12}\ x\ (300)\ x\ (530)^3\ x\ \frac{2}{530}}$$

- Hence flexural stress = 5.54 N/mm^2
- Width of beam = 300 mm & depth of beam = 530 mm taken
- M20 grade concrete is taken 5.54 N/mm^2 < 7 N/mm^2 (Flexural strength)

Hence O.K.

- Deflection due to flexural stress = $\frac{5}{24}\ x \frac{5.54\ x\ (6.6\ x\ 1000)^2}{25490\ x\ 530}$
- Using deflection due to U.D.L = $\frac{5}{24}\ x \frac{f\ l^2}{ED}$

$$E = 5700\sqrt{20} = 25490\ N/mm^2$$

- Hence deflection due to flexural stress = 3.72 mm
- Permissible deflection = $\frac{Span}{350}$ = 18mm > 3.72 mm

Hence O.K.

- *Deflection due to shear stress*

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Shear stress = $\frac{\frac{wl}{2}}{b\ d}$

$\frac{wl}{2} = \frac{1.43\ x\ 6.6}{2} = 4.72\ t$

Shear stress $= \frac{4.72\ x\ 1000\ x\ 10}{300\ x\ 530} = 0.297 N/mm^2$

- Shear strength of M20 grade concrete = $(20)^{0.333}$ = 2.712 N/mm^2 > 0.297 N/mm^2

Hence O.K.

- Flexural strength of M20 grade concrete = 7 N/mm^2 & shear strength = 2.712 N/mm^2
- Hence flexural stress is 2.58 times more than shear stress

Hence f = 2.58 x 0.297 = 0.766 N/mm^2

- Deflection of beam due to shear stress = $\frac{5}{24}\ x \frac{0.766\ x\ (6.6\ x\ 1000)^2}{25490\ x\ 530} = 0.515 mm$
- Permissible deflection due to shear stress = $\frac{18}{2.58} = 7.31\ mm > 0.515\ mm$

Hence O.K.

- Span = 8 m of beam $M = \frac{1.43\ x\ (8)^2}{8} = 11.44\ t-m$
- Using bending equation $\frac{M}{Z} = f$

$\frac{11.44\ x\ 1000\ x\ 10\ x\ 1000}{\frac{1}{12}\ x\ 300\ x\ (600)^3\ x\ \frac{2}{600}}$

f = 6.36 N/mm^2 < 7 N/mm^2

Hence O.K.

- Deflection due to flexural stress $= \frac{5}{24}\ x \frac{f\ l^2}{ED}$ = 5.533 mm
- Permissible deflection = $\frac{Span}{350}$=23 mm > 5.533 mm

Hence O.K.

- Shear stress = $\frac{\frac{wl}{2}}{b\ d}$

$= \frac{\frac{14.30\ x\ 8000}{2}}{300\ x\ 600} = 0.318\ N/mm^2$

- Since f = 2.58 x 0.318 = 0.820 N/mm^2
- Deflection due to shear stress = $\frac{5}{24}\ x \frac{0.820\ x\ (8000)^2}{25490\ x\ 600} = 0.714\ mm$
- Permissible deflection = For flexural stress = 23 mm

For shear stress = $\frac{23}{2.58} = 8.915\ mm > 0.714\ mm$

Hence O.K.

Relationship for flexural stress with Span of beam, Cross sectional area of beam

- *Case 1:* Span of beam = 6.6 m
- c/s of beam = 300 mm x 530 mm
- Flexural stress = 5.54 N/mm^2
- Flexural strength of concrete = 7 N/mm^2
- *Case 2:* Span of beam = 8 m
- c/s of beam = 300 x 600 mm
- Flexural stress = 6.36 N/mm^2
- Flexural strength of concrete = 7 N/mm^2 (M20 grade of concrete)
- *Formation of model*: are shown in table 1 and 2

Table 1. Data for span of beam, c/s of beam, flexural strength of concrete & flexural stress

S. N (1)	**Span of beam in meter (l)(2)**	**Cross sectional area of beam in m^2 (b x d) (3)**	**Flexural strength of concrete N/mm^2 (σcbc) (4)**	**Flexural stress in N/mm^2 (f)(5)**
(1)	6.6	0.16	7	5.54
(2)	8	0.18	7	6.36

Table 2. Data for $= \frac{l}{l_{\max}}, \frac{b\ xd}{(b\ x\ d)_{\max}}, \frac{\sigma cbc}{(\sigma cbc)_{\max}} \ \& \ \frac{f}{f_{\max}}$.

S. N (1)	$\frac{l}{l_{max}}$ **(2)**	$\frac{b\ x\rightleftarrows d}{(b\ x\ d)_{max}}$ **(3)**	$\frac{\sigma cbc}{(\sigma cbc)_{max}}$ **(4)**	$\frac{f}{f_{max}}$ **(5)**
(1)	0.825	0.890	1.000	0.871
(2)	1.000	1.000	1.000	1.000
Average	0.913	0.945	1.000	0.936

Corresponding to average value of $\frac{f}{f_{\max}}$ = 0.936 ≈ 1.000 value of $\frac{l}{l_{\max}}$ = 1.000, $\frac{b\ x\rightleftarrows d}{(b\ x\ d)_{max}}$ = 1.000 & $\frac{\sigma cbc}{(\sigma cbc)_{\max}}$ = 1.000 & average value of $\frac{l}{l_{\max}}$ = 0.913 , $\frac{b\ x\rightleftarrows d}{(b\ x\ d)_{max}}$= 0.945 &$\frac{\sigma cbc}{(\sigma cbc)_{max}}$ = 1.000

- Hence power of $\frac{l}{l_{\max}} = \frac{0.913}{1.000}$ = 0.913

[0.913 = Lesser value taken from corresponding value = 1.000]
Power of $\frac{b\ x\rightleftarrows d}{(b\ x\ d)_{max}}=\frac{0.945}{1.000} = 0.945$ & power of
$\frac{\sigma cbc}{(\sigma cbc)_{\max}} = \frac{1.000}{1.000} = 1.000$

- Hence model is

$$\frac{f}{f_{max}\left[\frac{l}{l_{max}}[]^{0.913}\left[\frac{b\ x\rightleftarrows d}{(b\ x\ d)_{max}}[]^{0.945}\left[\frac{\sigma cbc}{(\sigma cbc)_{max}}[]^{1.000}\right]\right]\right]}$$

Coefficient x taken to balance L.H.S = R.H.S of equation

- Average value of $\frac{f}{f_{\max}}$ = 0.936, $\frac{l}{l_{\max}}$ = 0.913, $\frac{b\ x\rightleftarrows d}{(b\ x\ d)_{max}}$ = 0.945, $\frac{\sigma cbc}{(\sigma cbc)_{max}}$= 1.000
- Hence equation will be

$0.936 = x\ [0.913]^{0.913}\ [0.945]^{0.945}\ [1.000]^{1.000}$
Hence
0.936 = x [0.920] 0.948] [1.000]
0.936 = 0.872 x
∴ x = 1.703
Hence model is

$$\frac{f}{f_{max}\left[\frac{l}{l_{max}}[]^{0.913}\left[\frac{b\ x\rightleftarrows d}{(b\ x\ d)_{max}}[]^{0.945}\left[\frac{\sigma cbc}{(\sigma cbc)_{max}}[]^{1.000}\right]\right]\right]}$$

- Predication from model:-

For span of beam = 7 m
c/s area = 300 mm x 550 mm & flexural strength = 7 N/mm^2
To find flexural stress for beam

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$$\frac{f}{f_{max}\left[\frac{7}{8}\right]^{0.913}\left[\frac{0.17}{0.18}\right]^{0.945}\left[\frac{7}{7}\right]^{1.000}}$$
= 1.073 [0.885] [0.947] [1.000]
= 0.899

- Hence flexural stress = 5.72 N/mm^2
- Validation of model:-
- Span of beam = 7 m
- Load on beam = 14300 x 7

$$\frac{100100}{10\ x\ 1000} \Rightarrow \ 10\ t$$
Hence load intensity
$$w \ = \frac{10}{7} \ = \ 1.43\ t/m$$
$$M \ = \frac{1.43\ x\ (7)^2}{8} \ = \ 8.76\ t - m$$
Flexural stress ⇒
Using bending equation
$$\frac{8.76\ x\ 1000\ x\ 10\ x\ 1000}{\frac{1}{12}\ x\ 330\ x\ (550)^2\ \frac{2}{550}}$$
$f \ = \frac{87600000}{16637500} \ = \ 5.27\ N/mm^2 \ < \ 7N/mm^2$ (flexural strength)

Hence safe & validated
- Span is variables & other parameters are constant in the derived model.
- Span is increased by 20%

$Span = \frac{20}{100}\ x\ 6.6 \Rightarrow 1.32\ meter$ increased

Hence span = 6.6 + 1.32 = 7.92 meter
Using model :-
- Taking span = 7.92 meter & other parameters are taken constant corresponding to l = 6.6. from Table.

Hence using the model:-
$$\frac{f}{f_{max}\left[\frac{7.92}{8}\right]^{0.913}\left[\frac{0.16}{0.18}\right]^{0.945}\left[\frac{7}{7}\right]^{1.000}}$$
= 1.073 [0.991] [0.895] [1.000]$^{1.000}$
= 0.899
$$\frac{f}{f_{max}[0.991][0.895]}$$
= 0.952
Hence flexural stress = 6.055 N/mm^2
- Increase in flexural stress corresponding to l = 6.6 m

In 5.54 N/mm^2 increase in flexural stress
= (6.055 – 5.54)
= 0.515 N/mm^2

In 1 N/mm2 increase in flexural stress $= \frac{0.515}{5.54}$
In 100 $\Rightarrow \ \frac{0.515\ x\ 100}{5.54} = \ 9.30\%$

Findings: Due to 20% increase in span the flexural stress is increased by 9.30% (b x d) taken as variable c/s area is increased by 20%.

Hence $\frac{20}{100} x\ 0.16\ =\ 0.032$
Hence c/s are = 0.16 + 0.032 $\Rightarrow$ 0.192m^2
Using the model: Other parameters constant corresponding

$$\frac{f}{f_{max}\left[\frac{6.6}{8}\right]^{0.913}\left[\frac{0.192}{0.180}\right]^{0.945}\left[\frac{7}{7}\right]^{1.000}}$$

$$\frac{f}{f_{max}[0.839][1.063][1]}$$

= 0.957
f = 6.09 N/mm^2

- Increase in flexural stress in 5.54 N/mm^2 increase in flexural stress
  = (6.09- 5.54)
  = 0.55 N/mm^2

$\therefore\ 1\ \frac{0.55}{5.54}$

$100\frac{0.55\ x\ 100}{5.54}\ =\ 9.928\%$

- *Findings*: Due to 20% increase in cross sectional area flexural stress is increased by 9.928%.
- Flexural strength of concrete is increased by 20% other parameters corresponding to span = 6.6 m taken constant.

Increase in flexural strength of concrete
$\frac{20}{100}\ x\ 7\ \Rightarrow 1.4\ N/mm^2$

Hence flexural strength taken as 7 + 1.4 = 8.4 N/mm^2

Using the model:-

$$\frac{f}{f_{max}\left[\frac{6.6}{8}\right]^{0.913}\left[\frac{0.16}{0.18}\right]^{0.945}\left[\frac{8.4}{7}\right]^{1.000}}$$

= 1.073 [0.839] [0.895] [1.20]
= 0.967
f = 6.149 N/mm^2

- Increase in Flexural stress due to 20% increase in flexural strength

In 5.54 N/mm^2 increase in flexural stress
= 6.149-5.54
= 0.609 N/mm^2

In $1\frac{0.609}{5.54}$
$100\quad \frac{0.609\ x\ 100}{5.54}\ =\ 11\%$

- *Findings*: Due to 20% increase in flexural strength of concrete we should take 11% increase in flexural stress.
- Hence we conclude flexural strength of concrete is dominant parameter for flexural stress as compared to span of beam & cross section of beam.

- Relationship for flexural stress & deflection of beam shown in Table 3 and 4

Table 3. Data for span of beam, depth of beam, flexural stress & deflection.

S. N (1)	Span of beam in meter (l)(2)	Depth of beam in mm (D)(3)	Flexural stress in N/mm^2(4)	Deflection in mm (δ)(5)
(1)	6.6	530	5.54	3.72
(2)	8	600	6.36	5.53

Table 4. Data for $\frac{l}{l_{max}\frac{D}{D_{max}\frac{f}{f_{max}\frac{\delta}{\delta_{max}}}}}$ (To get unit less in both sides of equation).

S. N (1)	$\frac{l}{l_{max}}$ (2)	$\frac{D}{D_{max}}$ (3)	$\frac{f}{f_{max}}$ (4)	$\frac{\delta}{\delta_{max}}$ (5)
(1)	0.825	0.883	0.871	0.673
(2)	1.000	1.000	1.000	1.000
Average	0.913	0.942	0.936	0.837

- *Output parameter*: $\frac{\delta}{\delta_{max}}$
- *Input parameter*: $\frac{l}{l_{max}}$, $\frac{D}{D_{max}}$ & $\frac{f}{f_{max}}$

Power of $\frac{l}{l_{\max}} = \frac{0.913}{1.000} = 0.913$

Where corresponding value of $\frac{l}{l_{\max}} = 1.000$ for average value of $\frac{\delta}{\delta_{\max}}$ = 0.837 ≈ 1.000 from Table.

- Similarly power of $\frac{D}{D_{\max}} = 0.942$ & $\frac{f}{f_{\max}} = 0.936$
- Hence model is

$$\frac{\delta}{\delta_{max}\left[\frac{l}{l_{max}}[]^{0.913}\left[\frac{D}{D_{max}}[]^{0.942}\left[\frac{f}{f_{max}}[]^{0.936}\right]\right]\right]}$$

Average value of $\frac{\delta}{\delta_{max}}, \frac{l}{l_{max}}, \frac{D}{D_{max}}$ & $\frac{f}{f_{max}}$ taken

Actually $\frac{\delta}{\delta_{max}}\alpha \frac{l}{l_{max}}\&\frac{f}{f_{max}}$ &$\frac{\delta}{\delta_{max}}\alpha \frac{1}{\frac{D}{D_{max}}}$

Hence

$$\frac{\delta}{\delta_{max}\left[\frac{l}{l_{max}}[]^{0.913}\left[\frac{1}{\frac{D}{D_{max}}}[]^{0.942}\left[\frac{f}{f_{max}}[]^{0.936}\right]\right]\right]}$$

Taking average value of $\frac{\delta}{\delta_{max}}, \frac{l}{l_{max}}, \frac{D}{D_{max}}$ & $\frac{f}{f_{max}}$ we have :-

$$0.837 = x \ [0.913]^{0.913} \left[\frac{1}{0.942}\right]^{0.942} [0.936]^{0.936}$$

= x [920] [1.056] [0.940]
= 0.913 x
∴ = 0.917

- Hence model is $\dfrac{\delta}{\delta_{max}\left[\frac{l}{l_{max}}[]^{0.913}\left[\frac{1}{\frac{D}{D_{max}}}[]^{0.942}\left[\frac{f}{f_{max}}[]^{0.936}\right]\right]\right]}$
- Span is variable & other parameters corresponding to l = 6.6m are taken constant from Table.

Increase in span = 20%

$\dfrac{20}{100}\ x\ 6.6 \Rightarrow 1.32\ m$

- l = 7.92 meter
- Using the model

$$\frac{\delta}{\delta_{max}\left[\frac{7.92}{8}\right]^{0.913}\left[\frac{1}{\frac{530}{600}}\right]^{0.942}\left[\frac{5.54}{6.36}\right]^{0.936}}$$

= 0.917 [0.991] [1.124] [0.879]

= 0.898

∴ δ = 4.966 mm

Increase in deflection

In 3.72 mm increase in deflection (4.966-372)

= 1.46 mm

$1\frac{1.246}{3.72}$

$100\frac{1.246\ x\ 100}{3.72}\ =\ 33.49\%$

- *Findings*: Due to 20% increase in span of beam deflection is increased by 33.49%

Depth of beam is increased by 20%

$\dfrac{20}{100}\ x\ 530 \Rightarrow 106\ mm$

Hence depth of beam :-

530 + 106 = 636 mm

Using the model: -

$$\frac{\delta}{\delta_{max}\left[\frac{6.6}{8}\right]^{0.913}\left[\frac{1}{\frac{636}{600}}\right]^{0.942}\left[\frac{5.54}{6.36}\right]^{0.936}}$$

$0.917\ =\ \ [0.025]^{0.913}\ \left[\frac{1}{1.06}\right]^{0.942}\ \ [0.876]^{0.936}$

= 0.817 [0.034 [0.947] [0.883]

$\frac{\delta}{\delta_{max}}$

δ = 0.127 mm

- Decrease in deflection due to increase in depth of beam.

In 3.72 mm decrease is 0.127 mm

$1 \frac{0.127}{3.72}$

$100 \frac{0.127 \ x \ 100}{3.72} = 3.41\%$

- Flexural stress is increased by 20%

$$\frac{20}{100} \ x \ 5.52 \Rightarrow 1.108 \ N/mm^2$$

Increase in flexural stress = 5.54 + 1.108 ⇒ 6.648 N/mm^2

- Using the model

$$\frac{\delta}{\delta_{max}\left[\frac{6.6}{8}\right]^{0.913}\left[\frac{1}{\frac{530}{600}}\right]^{0.942}\left[\frac{6.648}{6.36}\right]^{0.936}}$$

$$= 0.917 \ [0.839]^{0.913} \left[\frac{1}{0.883}\right]^{0.942} [1.007]^{0.936}$$

= 0.917 [0.839] [1.124] [1.007]

= 0.871

δ = 4.817 mm

- Increase in deflection

In 3.72 mm increase in deflection is (4.817-3.72) = 1.097 mm

$1 \frac{1.097}{3.72}$

$100 \frac{1.097 \ x \ 100}{3.72} = 29.49\%$

Findings:- Due to 20% increase in flexural stress deflection is increased by 29.49%.

- Hence we conclude that span of beam is dominant parameter for deflection of beam as compared to flexural stress & depth of beam.

Flexural rigidity $\frac{EI}{L}$

- Which parameter is dominant amount depth of beam or span of beam.
- Span ⇒ 6.6 m = l
- Width of beam =300 mm
- Depth of beam = 530 mm
- E = 25490 N/mm^2

In case I $\frac{EI}{L}$

$$= \frac{25490 \ x \ \frac{1}{12} \ x \ 300 \ (530)^3}{6.6 \ x \ 1000}$$

$$\frac{EI}{L} = \frac{87352452 \ t{-}m}{10 \ x \ 1000 \ x \ 1000} = 1438 \ t-m$$

Case II

L = 8m

$$\frac{EI}{L} = \frac{2549000 \ x \ \frac{1}{12} \ x \ 0.3 \ (0.6)^3}{8} = 1721 \ t-m$$

- *Findings*: If span of beam is more more deflection hence we require more flexural rigidity to keep beam equilibrium.

- *Formation of model*: Table 5 and 6

Table 5. Data for span of beam, depth of beam & flexural rigidity.

S. N (1)	**Span of beam in meter (L)(2)**	**Depth of beam in mm (D)(3)**	**Flexural rigidity in t-m$\left(\frac{EI}{L}\right)$ (4)**
(1)	6.6	530	1438
(2)	8	600	1721

Table 6. Data for $\frac{L}{L_{max}}$, $\frac{D}{D_{max}}$ & $\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}}$:- (To make unit less)

S. N (1)	$\frac{L}{L_{max}}$ **(2)**	$\frac{D}{D_{max}}$ **(3)**	$\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}}$ **(4)**
(1)	0.825	0.883	0.836
(2)	1.000	1.000	1.000
Average	0.913	0.917	0.918

Corresponding to $\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}}$= 0.918 ≈ 1.000

Value of $\frac{L}{L_{max}}$= 1.000

$\frac{D}{D_{max}}$= 1.000

Average value of $\frac{L}{L_{\max}}$ = 0.913 & $\frac{D}{D_{\max}}$ = 0.917

Hence model is :-

$$\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}\left[\frac{L}{L_{max}}[]^{0.913}\left[\frac{D}{D_{max}}[]^{0.917}\right]\right]}$$

or 0.918 = x [0.913]$^{0.913}$ [0.917]$^{0.917}$

= x [0.920] [0.924]

Hence 0.918 = 0.850 x

∴ x = 1.08

Hence model is

$$\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}\left[\frac{L}{L_{max}}[]^{0.913}\left[\frac{D}{D_{max}}[]^{0.917}\right]\right]}$$

- If D is increased by 20% & L is constant

$$\frac{20}{100}\, x\; 530 = 106\ mm$$

Hence D = 636 mm

Using model:-

$$\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}[0.825]^{0.913}\left[\frac{636}{600}\right]^{0.917}}$$

= 1.08 [0.839] [1.06]$^{0.917}$

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$$\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}[0.839][1.054]}$$

= 0.955

Hence $\frac{EI}{L}$ = 1644 t-m

- *Findings*: Increase in flexural rigidity:-

In 1438 t-m increase is 206 t-m

1 $\Rightarrow$ $\frac{206}{1438}$

100 $\Rightarrow$ $\frac{206 \ x \ 100}{1438} = 14.33\%$

- *Findings*: Due to 20% increase in depth of beam flexural rigidity is increased by 14.33%.

Case II: D is taken constant & span of beam is variable increase in span of beam = 20%.

$\frac{20}{100} \ x \ 6.6 = 1.32 \ meter$

Hence span of beam = 6.6 + 1.32 $\Rightarrow$ 7.92 m

Using the model :-

$$\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}\left[\frac{7.92}{8}\right]^{0.913}\left[\frac{530}{600}\right]^{0.917}}$$

$$\frac{\frac{EI}{L}}{\left(\frac{EI}{L}\right)_{max}[0.990]^{0.913}[0.883]^{0.917}}$$

= 1.08 [0.991] [0.892]

= 0.955

$\frac{EI}{L}$ = 1643

- Increase in flexural rigidity

In 1438 increase is (1643-1438) = 205

In 1$\frac{205}{1438}$

100$\frac{205 \ x \ 100}{1438} = 14.26\%$

- Increase in flexural rigidity due to 20% increase in span of beam = 14.26%.
- Hence we conclude due to increase in span of beam more deflection occurs hence we require more flexural rigidity to neutralize the deflection of beam.

Findings

Due to increase in depth of beam & span of beam flexural rigidity is increased by same amount.

CONCLUSIONS

Flexural stress & shear stress cause deflection & this deflection should be less than permissible value.

The study of deflection due to flexural and shear stresses highlights the intricate relationship between bending moments, shear forces, and material properties. Flexural stress, being the dominant factor, demands careful consideration in structural design. Ensuring that deflection remains within permissible limits is essential for maintaining structural integrity and functionality. Advanced materials and analytical methods provide opportunities to optimize designs, enhancing safety and performance.

- *Appendix*
- *Notation*

M =Bending moment in tonne-meter
Z =Sectional modules in m^3.
f =Flexural stress in N/mm^2.

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