

Beams on Elastic Foundations— Solution by Relaxation Methods

By W. Wright, B.Sc., Ph.D., A.M.I.C.E.

Several pure mathematical solutions have been obtained for beams resting on elastic foundations, see, for example, Timoshenko's "Strength of Materials," but these are restricted to certain standard types of loading and to constant flexural rigidity of the beam.

A practical application of these solutions is represented by a beam (usually concrete) resting on a soil which is assumed to have a constant subgrade modulus; this modulus, being the pressure necessary to deflect the foundation unit distance, has dimensions $(\text{lb./in.}^2)/\text{in.}$

In practice, there is a considerable variation in the value of the subgrade modulus, the assumed flexural rigidity of the beam and the assumed values of load. This is, therefore, a type of problem particularly suited to solution by Relaxation Methods¹—an exact solution is unobtainable but a solution to any required degree of accuracy is easily found. In view of the uncertainty of the other data, particularly the subgrade modulus, the degree of accuracy aimed at need not be exacting.

The relaxation method is readily adaptable to any type of loading and to any variation in flexural rigidity along the beam, whereas such variations tend to make the solution by pure mathematics very complex and tedious.

Governing Equation—

The governing equation is, from the usual beam theory,

$$EI \frac{d^4 y}{dx^4} + ky = w(x) = u,$$

where

x, y are Cartesian co-ordinates
 EI = the flexural rigidity of the beam
 $w(x)$ = the loading intensity at x
 k = Subgrade Modulus.

As a test of the relaxation method, the "standard case" of a central point load acting on a beam of uniform flexural rigidity has been worked out and checked against the solution as obtained by the more conventional treatment.

RELAXATION APPROACH

The beam is divided into a number of equal parts h apart. The governing equation is then expressed in finite difference form and values of the wanted function y are guessed at each point in the range. These values are substituted in the finite difference equations for the point and the resultant error or residual found. This is then liquidated by means of suitable operations, the final residual being made as small as we please, compatible with the accuracy required. When the deflections have been found, the practically important slopes and bending moments are easily calculated.

FINITE DIFFERENCE APPROXIMATION

The governing equation is $\frac{EI d^4 y}{dx^4} + ky = W(x) = u$,

and this must be expressed in finite difference form

$$\begin{array}{ccccccc} & a & & a & & a & & a & \\ & | & & | & & | & & | & \\ & \text{---} & & \text{---} & & \text{---} & & \text{---} & \end{array}$$

Considering 5 adjacent points of subdivision, the finite

difference form of $\frac{d^4 y}{dx^4}$ at the point x is $h^4 \left(\frac{d^4 y}{dx^4} \right)_x =$

$-\frac{1}{2}y_{x-2} + y_{x-1} + y_x$
 Differentiating twice and multiplying by h^4

$$h^4 \left(\frac{d^4 y}{dx^4} \right)_x = -\frac{24y_{x-2}}{h^4} + \frac{32y_{x-1}}{h^4} + \frac{16y_{x+1}}{h^4}$$

$$= -4(-4y_{x-2} + y_{x-1} + y_x) + 4y_{x-1} + 4y_x$$

$$= 16y_{x-2} - 16y_{x-1} - 16y_{x-1} + 16y_x + 16y_x$$

$\therefore$ The equation expressed in finite difference form is

$$-16y_{x-2} + 16y_{x-1} + 16y_{x+1} - 16y_x = y_x + \left(\frac{Wh^4}{EI} \right)_x$$

$$= \frac{16y_{x-2}}{EI} = u = P_x$$

The relaxation pattern for legislating residuals will be for the typical point x ,

$$\begin{array}{ccccccc} & & & +1 & & & \\ & & & | & & & \\ -1 & & a & & b & & -c \\ & & | & & | & & \\ & & \text{---} & & \text{---} & & \end{array}$$

In order to interpret the boundary conditions we need

also $\frac{d^2 y}{dx^2}$ and $\frac{d^3 y}{dx^3}$ expressed in finite difference form,

as follows:—

$$h^2 \left(\frac{d^2 y}{dx^2} \right)_x = -2\frac{1}{2}y_{x-2} + 2\frac{1}{2}(y_{x-1} + y_x) = \frac{2}{h^2} (y_{x-1} + y_x)$$

$$h^3 \left(\frac{d^3 y}{dx^3} \right)_x = 4y_{x-2} - 4y_{x-1} - 4y_{x+1} - 4y_x$$

¹ "Relaxation Methods in Engineering Science,"—Macmillan.

Solution Manual For Beams On Elastic Medium

Ying Liu



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 - The Rise of Digital Reading Solution Manual For Beams On Elastic Medium
 - Advantages of eBooks Over Traditional Books
2. Identifying Solution Manual For Beams On Elastic Medium
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
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 - Popular eBook Platforms
 - Features to Look for in an Solution Manual For Beams On Elastic Medium
 - User-Friendly Interface
4. Exploring eBook Recommendations from Solution Manual For Beams On Elastic Medium
 - Personalized Recommendations
 - Solution Manual For Beams On Elastic Medium User Reviews and Ratings
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 - Participating in Virtual Book Clubs
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 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
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 - Setting Reading Goals Solution Manual For Beams On Elastic Medium
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Solution Manual For Beams On Elastic Medium
 - Fact-Checking eBook Content of Solution Manual For Beams On Elastic Medium
 - Distinguishing Credible Sources
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 - Utilizing eBooks for Skill Development

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- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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