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A Novel Approximate Method for Analysis of High-Rise building Frames

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ABSTRACT

Statically Indeterminate structures that can more frequently occur in practice than the statically determinate ones are more economical because of their higher strength and stiffness. The choice between statically determinate and statically indeterminate structure depends on to largely the purpose for which a particular structure is required. These days, practically all major buildings are framed structures. Rigid jointed reinforced concrete frames are mostly used for High-Rise buildings, industrial structures, multilevel parking structures etc. The rigid High- rise building frames made with beam-column joints can resist bending moment, shear and axial forces, thus resulting in a highly indeterminate structure. Analysis of frame is possible through Kani's method or matrix methods, but solution by iteration or equation solving or matrix inversion process is tedious and time consuming for several loading cases. For quick analysis, design engineers use the approximate methods of analysis. The author's evolved novel approximate method is very useful to design engineers because substitute frame can quickly analyze with almost 90 to 95 % accuracy in comparison to exact analysis. The analysis steps are demonstrated with substitute frame example.

Keywords: Approximate Analysis, Substitute Frame, High-Rise Building, Relative Deformation Co-Efficient.

I. INTRODUCTION

Kanat Burak Bozdogan and Duygu Ozturk[1] have presented an approximate method based on the continuum approach and transfer matrix method for free vibration analysis of multi bay coupled shear wall. They conclude that the method is simple and accurate. An approximate hand method for estimating horizontal deflections in high-rise steel frame with flexible beam-column connections subjected to horizontal loading is presented by J. C. D. Hoenderkamp and H.H. Snijder [2].They conclude that the information obtained from this method should give the design engineer an easy means of comparing the suitability of alternative structural proposals, in addition to providing initial structural data for a more accurate analysis, or allowing a check on the reasonableness of the final output of a computer analysis. R.A.Behr, C.H.Goodspeed, R.M.Henry [3] have present the note to alert structural engineers to the potential errors in textbook methods of approximate structural analysis. They conclude that inappropriate assumptions in the approximate analysis of vertically loaded rectangular frames can lead to significant errors. A reliable ,reasonably accurate approximate method of structural analysis for symmetric, rectangular frames under symmetric vertical loading has been developed by R.A.Behr,E.J.Grotton and C.A.Dwinal[4].Okonkwo V.O, Aginam C.H. and Chidolue C.A[5] developed the mathematical model for evaluation of the internal support moments of a uniformly loaded continuous beam of equal span and the number of spans, taking the uniformly distributed load on the beam to be equal for all spans. An overview of various approximate method was briefly done by Life John and Dr. M.G. Rajendran[6].This paper also intends to compare revised method of structural analysis to the values obtained from STAAD.pro. Design charts are developed for selection of beam and reinforcement when the beam moment is available by S.N.Khuda and Anwar [7].

Numerous classical and traditional methods are well documented in the literature for the analysis of Indeterminate Structures. Statically Indeterminate structures that can more frequently occur in practice than the statically determinate ones are more economical because of their higher strength and stiffness. The choice between statically determinate and statically indeterminate structure depends on to largely the purpose for which a particular structure is required.

Structurally a building may consist of load bearing walls and floors. The floor slabs may be supported on beams which in turn may be supported on wall or columns. But, for a multistoried structure a building frame either of steel or of reinforced concrete is made. This frame is designed for all the vertical and horizontal loads transmitted to it. The openings between the columns, where necessary will be filled with brick walls. A frame of this type will consist of columns and beams built monolithically forming a network. This provides rigidity to the connections of members [8,9,10].

These days, practically all major buildings are framed structures. Rigid jointed reinforced concrete frames are mostly used for High-Rise buildings, industrial structures, multilevel parking structures etc. The building frame is the most common structural form, where the beams and columns are rigidly connected, typically in the reinforced concrete High- rise building frames where the joints are monolithic. The rigid High-rise building frames made with beam-column joints can resist bending moment, shear and axial forces, thus resulting in a highly indeterminate structure.

II. METHODS AND MATERIAL

2.1 Necessity of Approximate Methods

In the case of High-rise frames, the degree of indeterminacy is very high and hence analysis by classical methods like consistent deformation, slope deflection, moment distribution or column analogy method is ruled out. Analysis of frame is possible through Kani's method or matrix methods, but solution by iteration or equation solving or matrix inversion process is tedious and time consuming for several loading cases. For quick analysis, design engineers use the approximate methods of analysis.

Theoretically, a load applied at any point of a High-rise frame should cause reaction at all sections of frame. The effect of loads on distant panel is small. Thus, for the determination of moments in any member of a frame, only a small portion of the frame consisting of adjacent members only is analysed.

Such a small portion is termed 'Substitute Frame'. By analysing the substitute frames the moments can be calculated and results obtained are in good agreement with the results obtained from rigorous analysis [11,12].

2.2 Terminology and Steps for Analysis

The method is dependent on four inter-dependent and new terms formulated. These terms are explained as under.

A. Corrected member stiffness(K)

Corrected member stiffness of a frame member is multiplication of fixity coefficient(Cf) with relative flexural stiffness(EI/L) of frame member.

$$K = Cf \times EI/L \qquad (1)$$

B. Relative deformation co-efficient(Cr)

Relative deformation coefficient is defined as the deformation at far end of a frame member due to unit deformation applied at near end.

If unit rotation is applied to the near end of a fixed beam then values Cr and Cf at far end are 0 and 1 respectively due to fixed support at far end. But in case of propped cantilever, If unit rotation is applied to fixed near end then Cr and Cf are 0.5 and 0.75 respectively due to simple support at far end. In substitute frame extreme supports are taken as fixed supports, but if one intermediate member is considered then far end is neither fixed nor simple. At such location value of Cr is dependent on fixity of far end and it is computed using following relation.

$$Cr = K / 2\sum K \qquad (2)$$

C. Fixity Co-efficient(Cf)

Fixity coefficient gives the fixity provided against rotation by far end. The value of Cf at near end is always taken as unity while the same at far end is dependent on relative deformation coefficient Cr at far end. This is computed using following relation.

$$Cf = 1 - Cr/2 \qquad (3)$$

D. Actual Deformation(Ad)

Actual deformation of joints is deformation of that joint due to some deformation applied at any joint. Actual deformation of a joint is computed by multiplying actual deformation of preceding joint with relative deformation coefficient of the joint and it is expressed in equation form as under.

Adi = -Ad(i-1) X Cri (4)

where i is = joint index.

E. Steps for Analysis

Procedural steps to be followed for solution of substitute frame are as under.

Step1:

Choose suitable sign convention for forces and deformation.

Step2:

Compute value Cr and Cf at all joints except where joint moment is required. Start computing Cr and Cf from extreme supports and move towards joint where value of the moment is required.

Step3:

Take Ad = Φat a joint where value of moment is required and start computing Ad at each joint toward extreme supports. Here the value of Φ will be computed using following equation.

Φ = 1- K/∑K (5)

Steps 2 and 3 are to be repeated for all locations where joint moment is required.

Step4:

Compute fixed end moment at every joint for a particular load case. Compute the summation of multiplication of fixed end moment (FEM) at joints with actual deformation (Ad) at that joint for particular joint moment. This summation is nothing but required joint moment M.

M = ∑FEMi X Adi (6)

Where, i = Joint index.

Step 4 is to be repeated to get moment at the same and other joints with different load cases.

2.3 Approximate Analysis of Substitute Frame

In this method computation of Cr and Cf can obtained at different joints. Once the Cr has been obtained it is very easy to calculate the moment at required joint. In present study authors have evolved simple yet equally effective and novel method of approximate analysis. To illustrate the application of Approximate approach the substitute frame as shown in Fig.1 is taken and results are depicted in Table-II.

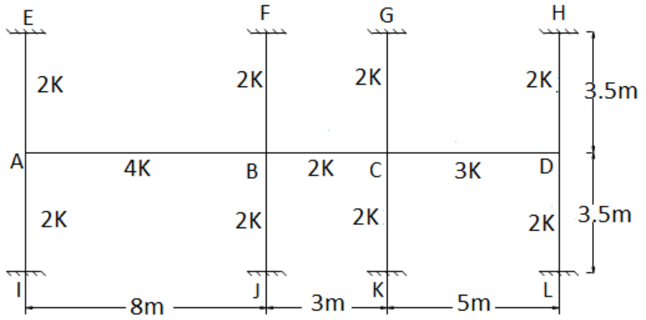

Figure 1: A substitute frame taken for example

As approximations for compute Cr and Cf will be taken as per following Table I.

TABLE I

Number of member meeting at a joint	*C r*	*Cf*
Two	1/4	7/8
Three	1/6	11/12
Four	1/8	15/16

Computation of Cr and Cf for negative moment in member AB at joint A.

At extreme joint D

Cr_{C-D} = 1/6 = 0.1667 (Three members meeting at joint D)

Cf_{C-D} = 11/12 = 0.9167

Cr_{B-C} = 1/8 = 0.125 (Four members meeting at joint C)

Cf_{B-C} = 15/16 = 0.9375

Cr_{A-B} = 1/8 = 0.125 (Four members meeting at joint B)

Cf_{A-B} = 15/16 = 0.9375

Computation of A_d for negative moment in member AB at joint A.

$$\phi_{AB} = 1 - \frac{K_{AB}}{K_{AB} + K_{AE} + K_{AI}} = 1 - \frac{0.9375x4K}{0.9375x4K + 2K + 2K}$$

$$= 0.5161$$

$A_{d \cdot A}$ = 0.5161

$A_{d \cdot B}$ = -$A_{d \cdot A}$ x $C_{r.\ B}$ = - 0.5161 x 0.125 = - 0.06451

$A_{d.C}$ = - Ad $._B$ x $C_{r \cdot C}$ = - (- 0.06451) x 0.125 = 0.0081

$A_{d \cdot D}$ = -$A_{d \cdot C}$ x $C_{r \cdot D}$ = - 0.0081 x 0.1667 = - 0.00135

Similarly Cr, Cf and Ad are computed for other joints and listed in Table-II

Live load is taken on span AB to get maximum negative bending moment at joint A. Respective Fixed End Moment is taken from Table-III.

$M = \sum Ad_{AB} X FEM$
= 0.5161X 20000 + -0.06451X (- 20000 + 12750) + 0.0081 X (- 12750 + 37500) + - 0.00135 X - 37500
= 10939.56 N.m (Ref ans.= 11229.46 N.m)
= % Error 2.58.
Similarly bending moment is calculated at various locations for different load cases and that are listed in Table-IV.

III. RESULTS

TABLE II

	A	B		C		D
Cr	---	0.125		0.125		0.1667
Cf	---	0.9375		0.9375		0.9167
Ad_{AB}	0.5161	- 0.06451		0.0081		- 0.00135
	A	**B**	**B**	**C**		**D**
Cr	0.1667	---	---	0.125		0.1667
Cf	0.9167	---	---	0.9375		0.9167
Ad_{BA}	- 0.1026	0.6157	0.3843	- 0.048		0.008
	A	**B**		**C**	**C**	**D**
Cr	0.1667	0.125		---	---	0.1667
Cf	0.9167	0.9375		---	---	0.9167
Ad_{CD}	0.007	- 0.04		0.3188	0.6812	- 0.11
	A	**B**		**C**		**D**
Cr	0.1667	0.125		0.125		---
Cf	0.9167	0.9375		0.9375		---
Ad_{DC}	- 0.002	0.009175		- 0.0734		0.5872

TABLE III

Member	Fixed End moment due to Dead Load N.m	Fixed End moment due to Total Load N.m
AB	101330	20000
BC	12750	27750
CD	37500	70170

TABLE IV

Maximum Moments	*Live load Position*	*Magnitude N.m*	*Percentage Error %*
Negative B.M at A	On AB only	10939.56	2.58
Negative B.M at B	On AB and BC	24262.33	4.76
Negative B.M at C	On BC and CD	60712.69	3.10
Negative B.M. at D	On CD only	46433.8	2.44

IV. CONCLUSION

Matrix inversion, Equation solving and Iterations are completely eliminated and the evolved method gives speedy and nearly accurate joint moments. The novel approximate method can always be adopted for a rapid check. The method evolved is novel for the analysis of High-rise frame, which gives near accurate results. The approximate method is very useful to design engineers because substitute frame can quickly analyze with almost 90 to 95 % accuracy in comparison to exact analysis.

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