"DYNAMIC RESPONSE OF DAMAGED-REPAIRED-STRENGTHENED PLANE OR SPACE STRUCTURES"

C.A. SYRMAKEZIS (I)
E.D. VOYATZIS (II)
Presenting Author: C.A. SYRMAKEZIS

SUMMARY

An analytical method is presented for the accurate calculation of the stiffness and though of the dynamic characteristics of a structure after damage or strengthening of some of its members. The method is based on the calculation of the stiffness of each individual member of the structure, performed using the transfer matrix method.

INTRODUCTION

In this paper, the results of a research project undertaken by the authors in the National Technical University of Athens, refering to the problem of the calculation of redestribution of action effects in a structure due to a damage or strengthening of some members, are presented. The modification of the flexural as well as torsional response of the members is considered.

To take into account, during the analysis of a R.C. element, the effects of local defects and the deterioration such as cracks, loss of strength or loss of section, is in general a difficult task. In the present paper the general principle of a new (modified) stiffness for the damaged region of the element may appear either to the stiffness versus deflection, mainly for beams and columns (initial value EJ, new value (EJ)′, variation Δ (EJ), E= =Modulus of Elasticity, J=moment of inertia), or to the stiffness versus axial shortening, mainly for columns (initial value EA, new value (EA)′, variation Δ (EA), A=section), or to the stiffness versus angular deformations mainly for walls and columns (initial value GA, new value (GA)′, variation Δ (GA), G=shear modulus).

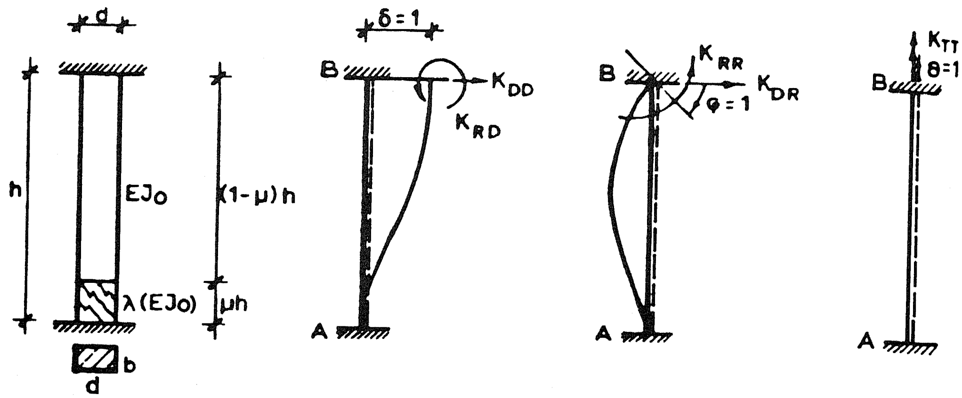
The analysis is performed through a special computer program, using the transfer matrix method of linear analysis. Three analytical models for the damaged area are used, properly selected according to the damage type and level (Ref. 2).

FLEXURAL AND TORSIONAL STIFFNESS MODIFICATION OF A DAMAGED MEMBER AND STRUCTURE

For the calculation of the stiffness matrix of a damaged member, the member is divided into damaged and undamaged parts and

(I) Dr. Civil Engineer, Lecturer, NTUA

(II) Civil Engineer, Research Fellow, NTUA



$$\begin{bmatrix} Q \\ M \\ T \end{bmatrix} = [K] \begin{bmatrix} \delta \\ \varphi \\ \theta \end{bmatrix} = \begin{bmatrix} K_{DD} & K_{DR} & 0 \\ K_{RD} & K_{RR} & 0 \\ 0 & 0 & K_{TT} \end{bmatrix} \begin{bmatrix} \delta \\ \varphi \\ \theta \end{bmatrix}$$

$$[K] = \begin{bmatrix} \rho_{DD} K_{O\,DD} & \rho_{DR} K_{O\,DR} & 0 \\ \rho_{RD} K_{ORD} & \rho_{RR} K_{ORR} & 0 \\ 0 & 0 & \rho_{TT} K_{OTT} \end{bmatrix}$$

$$K_{O\,DD} = \frac{12\,EJo}{h^3} \qquad K_{O\,DR} = -\frac{6\,EJo}{h^2}$$

$$K_{ORD} = \frac{6EJo}{h^2} \qquad K_{ORR} = -\frac{4EJo}{h}$$

$$K_{O.TT} = \frac{BJ_T}{h} \qquad J_o = bd^3/12$$

Fig. 1

$$J_T = 4\left(\frac{b}{d}\right)^2 \left[1 - 0.630\frac{b}{d} + 0.052\left(\frac{b}{d}\right)^5\right] . J_o$$

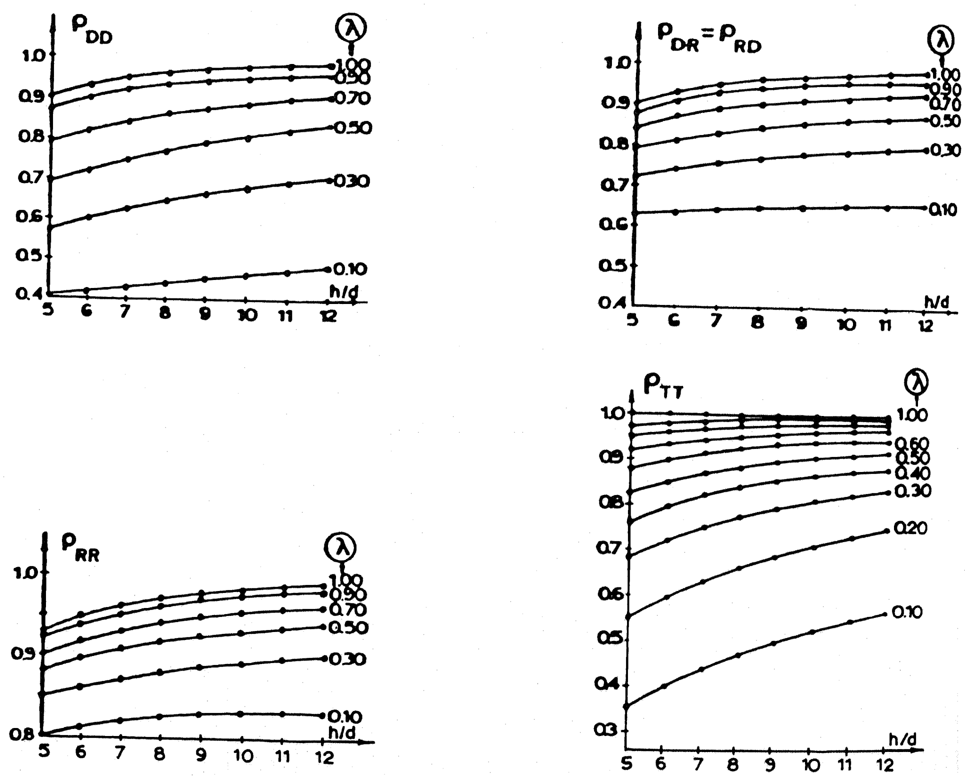


Fig. 2

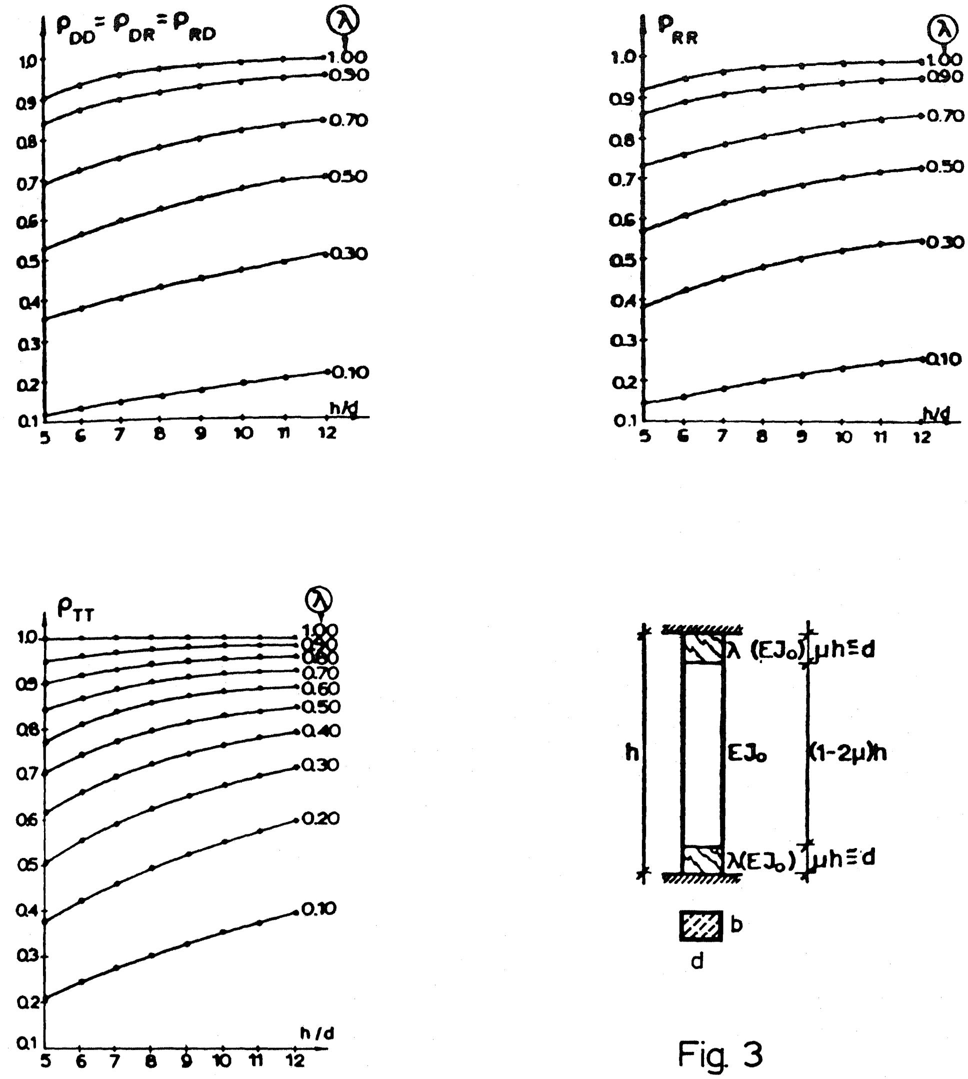


Fig. 3

the transfer matrix method is used. On figure 1, the case of a member damaged at one end (bottom) is presented. As shown on this figure, the values of the elements of the stiffness matrix are presented as percentages ρ of the initial values for the undamaged members. The variation of these four coefficients ρ_{DD}, $\rho_{DR}=\rho_{RD}$, ρ_{RR}, ρ_{TT} are shown for this case of figure 2, as a function of the ratio h/d (h=member length, d=section height) for various values of the percentage of diminuation λ for the damaged area of the initial stiffness EJ_o for a lenght of the damaged area μh equal to d. Similar diagrams for the case of a member damaged at both ends, are given on figure 3.

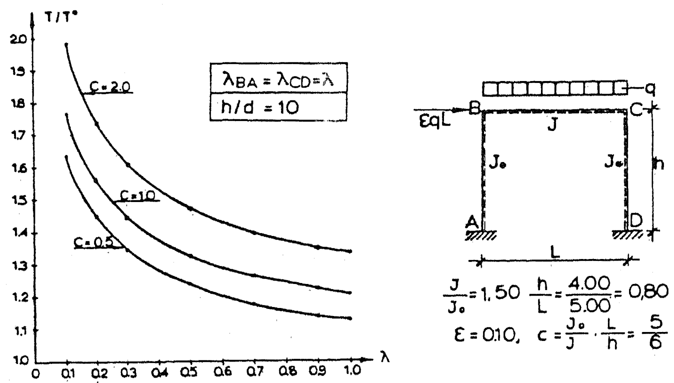

T / T°
C = 2.0
C = 1.0
C = 0.5
λBA = λCD = λ
h/d = 10
λ
εqL
q
B
C
J
J₀
J₀
h
A
D
L
J/J₀ = 1.50 h/L = 4.00/5.00 = 0.80
ε = 0.10, c = J₀/J · L/h = 5/6

Fig. 4

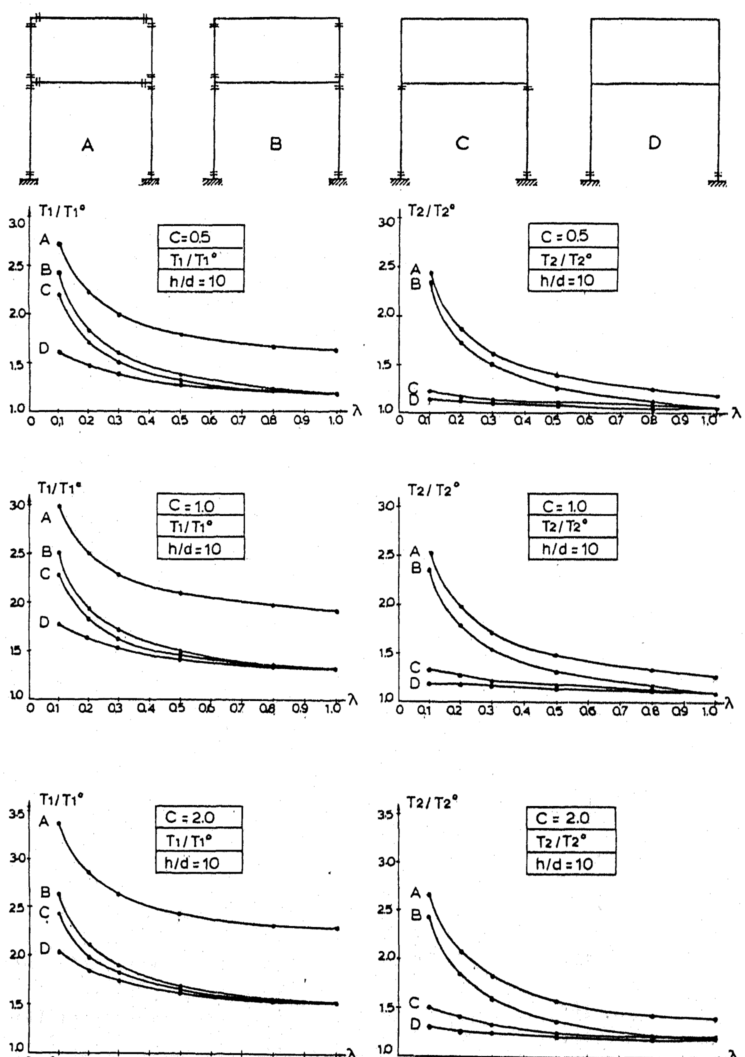

A
B
C
D
T1/T1°
C = 0.5
T1/T1°
h/d = 10
T2/T2°
C = 0.5
T2/T2°
h/d = 10
C = 1.0
T1/T1°
h/d = 10
C = 1.0
T2/T2°
h/d = 10
C = 2.0
T1/T1°
h/d = 10
C = 2.0
T2/T2°
h/d = 10
λ

Fig. 5

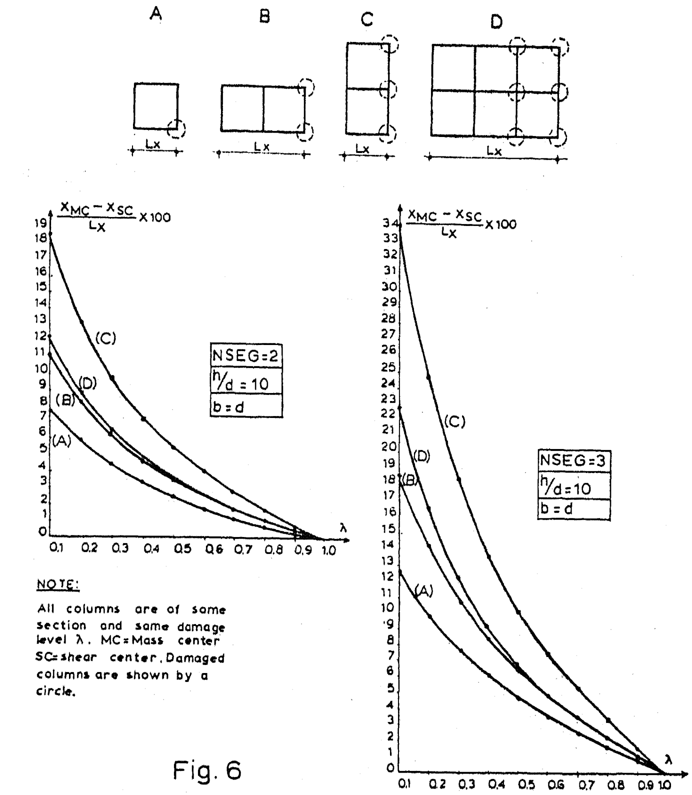


Fig. 6

The conclusion from these formulas and diagrams is that the values of the four coefficients ρ for each pair of values h/d and λ are significantly different and thus, it is not possible to assume a constant diminuation of the stiffness of the column, in order to take into account the diminuation λ for the damaged part.

The modification of the member stiffness has a direct influence on the stiffness and though on the dynamic characteristics of the overall structure. As a first example, the simple frame of figure 4 is considered. The geometrical characteristics are given on the figure. The two columns BA, CD are damaged at the bottom with the same stiffness diminuation λ. On the figure, the variation of the ratio of fundamental period T to the equivalent period T^o of the undamaged shear building is given as a function of the stiffness diminuation percentage λ of the damaged area of the columns for three values of the constant c=0.5, 1.0, 2.0 and for h/d =10. As a second example, on figure 5, the case of a two storey frame is considered, for 4 different cases of damage A,B,C,D (damaged area is shown with the "=" sign). For these four cases, the variations T_1/T_1^o and T_2/T_2^o of the two self-periods of the frame are presented, for the same three values of the constant c, and h/d=10, as a function of λ. It is to be noted that the variation of c has a small influence on the second period, while in general, all variations are more important for the smaller values of λ, which corresponds to a higher damage level.

On figure 6, the case of the displacement of the shear center due to the damage of some columns of ... four types of structures is considered. On the two diagrams, the variation of the ratio of the displacement of the shear center to the total length of the structure is shown for the case of columns damaged at the one end (NSEG=2) and at the both ends (NSEG=3), for h/d=10 and b=d. As shown on the figure, the variation of this displacement, which directly may influence the torsional response of the structure, is important. Among the four cases considered, case C presents the bigger deviations.

FLEXURAL AND TORSIONAL STIFFNESS MODIFICATION OF A REPAIRED AND/ /OR STRENGTHENED MEMBER AND STRUCTURE

The member stiffness is significantly modified after repair and/or strengthening through a jacket. For the calculation of this stiffness, the damaged member and the jacket are considered to be connected in some discrete points, which are considered to have common generalized displacements for both member and jacket. This assumption results the appearence of horizontal and vertical unknown interaction forces between jacket and column at these points. This connection can be absolutely rigid or permitting relative vertical slip, which is expressed as a difference in rotation angle between the connected points (Fig. 7). The displacements and rotations of the sections are calculated separately for the damaged column and the jacket. The compatibility of these deformatins leads to the calculation of forces transmitted from jacket to column and oppositely, for unitary displacement $\delta=+1$, unitary rotations $\varphi=+1$ and $\vartheta=+1$ at the top end of the system. The elements of the final stiffness matrix of the system is the algebraic sum of the reactions at the top of column and jacket, due to the aforementioned unitary deformations, as well as to their loading with the equivalent interactive forces.

Using a special computer program written according to this procedure, a great number of cases have been investigated. This investigation leads to the conclusion that the upper limit of the stiffness of the system jacket-member appears always in the case of a rigid connection between the two parts. This stiffness is smaller than the stiffness of the system considered as a unique section. The lower limit is the stiffness of the jacket itself. All cases of slip between jacket-member give results between these two limits. On figure 8, the variation of the first of the four coefficients ρ of the stiffness matrix is given indicatively as a function of the ratio h/d of the column , for various values of the ratios d/b of the dimensions of the column section and h/t, where t is the thickness of the jacket. Similar diagrams can be given for the other three coefficients ρ. It is to be noted that

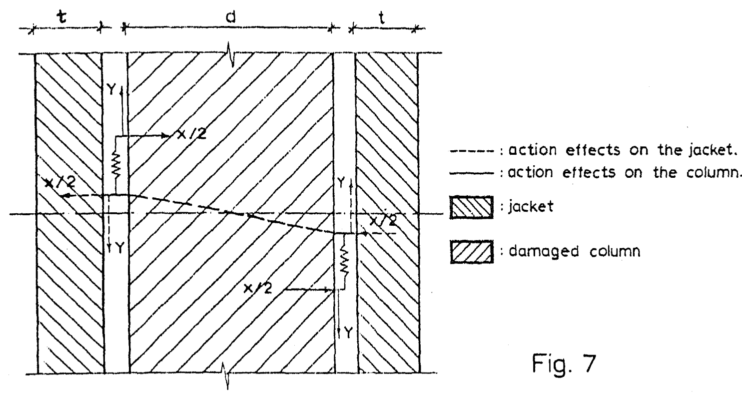


Fig. 7

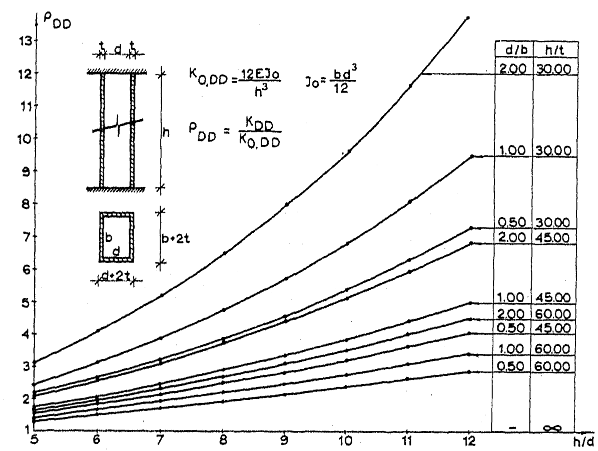


Fig. 8

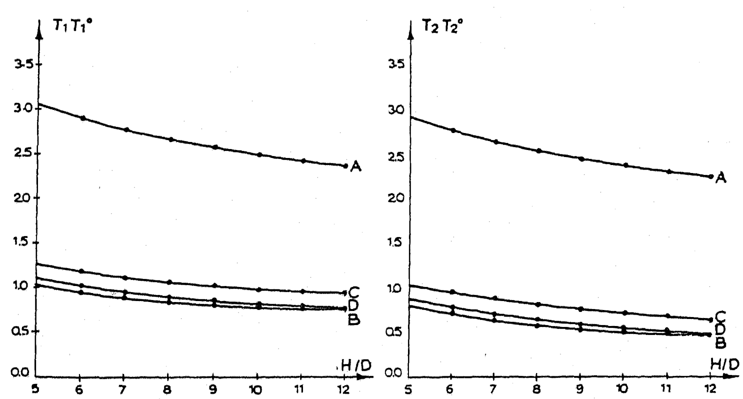


Fig. 9

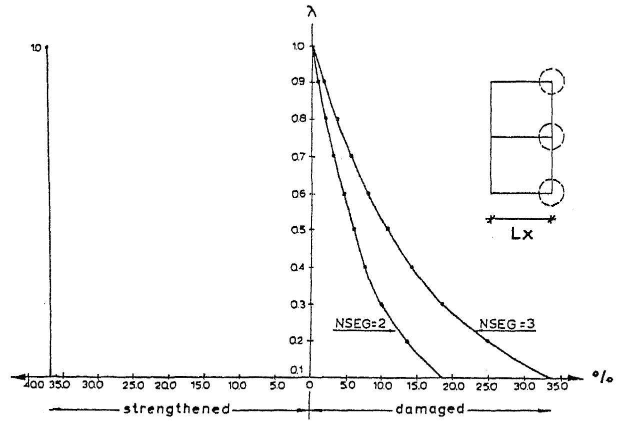


Fig. 10

while the differences between the various damage levels (expressed as variation of λ) are important for a damaged member, for the case of a jacket-strenghtened member are of minor importance. This is clear for the case of the displacement of the shear center, due to the damage of some columns, where after strengthening through jacketing, the displacement is almost constant, for all values λ (fig. 10).

On figure 9, the variations of the ratios T_1/T_1^o and T_2/T_2^o are shown as a function of h/d, for the case B of the example of figure 5, for c=1.0 and λ=0.10. Curve A, corresponds to the damaged structure, curve B to the repaired/strengthened structure through jacketing with h/t=30 and rigid connection, curve C, for h/t=60, and curve D for h/t=30 and slip between jacket - member, with spring constant equal to 50. The influence of the jacket strengthening on the dynamic characteristics of the structure is obvious on this figure.

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