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Nonlinear Geometric Material and Time-Dependent Analysis of Reinforced and Prestressed Concrete Frames

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NONLINEAR GEOMETRIC, MATERIAL AND TIME DEPENDENT
ANALYSIS OF REINFORCED AND PRESTRESSED CONCRETE FRAMES

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Young-Jin Kang

Faculty Investigator: \overline{a} $\ddot{\Omega}$ Scordelis

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College of Engineering
Office of Research Services University of California

Berkeley, California

January 1977

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ACKNOWLEDGEMENT

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S these e^s(t), aging e^{nm}(t) consists and ϵ^s (t) and Intraxi strains, concrete ϵ^{m} (t), ϵ^{c} (t), niarain ϵ ^t(t) $\frac{0}{n}$ **SEZES** ϵ^{a} (t) creep **BIR** non-stress strain ec ϵ^{a} (t) are and thermal $\frac{\omega}{\pi}$ time a
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10 \blacktriangleright \boldsymbol{v} \pmb{u}_i tress-strain E_Td. Such different made compressive speeds \mathbf{z} n ω $\tilde{}$ rt. \mathbf{r} \mathbf{N} and curve ain $\stackrel{\bullet}{\mathbf{p}}$ Concrete the $\frac{0}{3}$ compressive swous nearrenents relationship can a n stres e d A p e exially $\frac{1}{2}$ ិ
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آقا \overline{z} . \overline{z} $\frac{0}{12}$ **also** than in determined brittie $\frac{1}{4}$ \mathbf{p} e ne that $F19.$ i
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M $\begin{array}{c} 1 \ 1 \ 0 \ 1 \end{array}$ affected compressive stress-strain curve o s T a larger the $\ddot{}$ \mathbf{z} high-strength $\begin{array}{c} 1 \ \hline 0 \end{array}$ $\frac{1}{\sigma}$ **Seen** \mathbf{z} initial \bullet $\frac{1}{2}$ n a p fracture ーーロー (54) that the that compressive modulus Ħ concrete ø concrete $\frac{1}{10}$ sanao $\frac{0}{n}$ $\frac{0}{n}$ concrete $\frac{0}{n}$ application $\frac{0}{n}$ $\pmb{\mu}$ concrete strength. \mathfrak{r} **Phe** ø Iower edzer havin shape \bullet m hav- $\frac{0}{n}$ Ħ ۱Ó $\frac{0}{1}$ $\sum_{i=1}^{n}$

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D often mentioned. **p** jected to Ω e
S p. rt oncrete specimens such as cylinders, cubes and prisms, subtely. rain the
b influenced numixvu era × consideration in design practice. 512e t1me \vec{v} relationship of concrete is largely determined by the United concrete structures for long-time loading more in. this variation of its compressive strength, ۰۰.
Ca $\frac{0}{n}$ gain in strength can be noted. Tetxetun well aggragate and gain of strength with time are cylinder, denoted neworks is shown $\frac{1}{2}$ States. average many factors, among which waterknown, but The increase in the strength of concrete conpression. stess optained from the The compressive strength of in strength with time in order r.
J $\frac{1}{4}$ by f., is most commonly used is not Lg. **Fhe** N
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e and **Eype** ed A₁ e d A₁ edA₁ stress-strain relationship of necessary tool. III III \mathbf{H} I cement $\frac{0}{1}$ $\frac{1}{2}$ cement concrete cement cement idealizations Popovics $\ddot{}$ 44 $a = 4.00$, $\bullet\bullet$ a=1.00, $\ddot{}$ $a = 2.30$, structure. a=0.70, (85) Many e z e 56.0*0 $58.0 - 9$ empirical 86'0-8 $26.0 = 9$ Some of UMOUS Q)

Kas to mode1. labs used Fig. and phia is ζ $2.4.8$ shells. Lin **Phe BRONB** $\frac{2}{3}$ simplest Th his rudy ø linearly of nonlinear elastic-perfectly $\frac{0}{l}$ reinforced concrete models. plastic This model

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G $-54.$ $\frac{0}{n}$ conc (12) and Aldstedt approximated $2.4.4$ reinforced 22362 rete model capable of shons pasn in. unich प
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ສຸ concrete $\mathbf{\hat{p}}$ piecewise $\pmb{\omega}$ etailable Comp Off (47) used this model in their ្អ
ត្ **Seites** experimental frames. representing this $\frac{0}{n}$ linear straight line model is restricted Although model data wide variety in which $rac{1}{2}$ this segments. e n e r
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modi vestigators the their concrete gested by Hognestad ebiu present fications. variety seigies columns, investigation kroenke, et $\frac{0}{10}$ $\frac{0}{m}$ This model has concretes prestressed Wilhelm, (60) , al (61) in their this and $\frac{1}{n}$ क
रो concrete $\hat{\mathbf{p}}$ is shown $\frac{1}{2}$ heen mathematical nodel (25) widely used is utilized columns, and Aroni in Fig. 2.4.c. study Ecrmula $\frac{1}{\sigma}$ $\frac{1}{2}$ $\widehat{\circ}$ $\frac{0}{10}$ **Mith** $5, 5, 64$ **Daman** many slender ria
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\varepsilon_0 = \frac{2 \, \varepsilon^{\, \text{H}}}{\varepsilon^{\, \text{H}}} \tag{2.11}
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E_{\rm t} = \frac{d\sigma}{d\epsilon^m} = E_{\rm i}(1 - \frac{\epsilon^m)}{\epsilon_0})
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b peak point a fession contain the fession 변 given ប្អូង above, $\ddot{ }$ twice e u a $\frac{1}{n}$ $\frac{1}{\alpha}$ e u a tangent modulus **DOCE** magnitude a parabola that .. $\frac{0}{n}$

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Q $\frac{1}{2}$ this study, zero. of this mechanical compressive the ang value part **the** e u a strain reduces Stress-strain can decrease tangent o
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ing $\frac{0}{10}$ Aldstedt the initial formula, けごのべの (47) **RNS** numerous empirical tangent modulus, ACI Committee 502 $\begin{bmatrix} 1 \\ 2 \end{bmatrix}$ (56) recommends formulas They か
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位 707 **Summarized** $\frac{1}{2}$ ene
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To viscous mechanical (69) Fact flow theory (68), deformation theory OLS influencing and $\ddot{\Omega}$ $\frac{1}{2}$ $\ddot{\bullet}$ sepage (66), plastic Þ O
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T $\frac{1}{2}$ loading τ н first the in the စ်
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50 \mathbf{u} \mathbf{r} developed 一つの話 റ $\ddot{\bullet}$ $\frac{0}{3}$ \circ $\pmb{\omega}$ $30₀$ intensity, Ω H $\frac{1}{2}$ $\ddot{\mathbf{u}}$ \mathbf{u} ţú. **Heep** đ. $\frac{0}{n}$ the
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रा stain \bullet stresspresent ratio \mathfrak{a} u
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نه **SERRES** $\overline{\mathbf{v}}$ $\frac{0}{5}$ based ia
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m \blacksquare pue then n d c reas $\pmb{\mathsf{\Omega}}$ m aieain $\frac{1}{2}$ $\vec{\circ}$ 005 $\frac{\rho}{\sigma}$ $\ddot{\phi}$ \mathbf{r}_1 (92)

the. g e g Commitee σ $\overline{\sigma}$ $\ddot{\mathbf{o}}$ C. \mathfrak{a} Þ \mathbf{u} prediction \mathbf{a} redic \mathbf{r}_h $\mathbf{\tau}$ $\frac{0}{3}$ **BULDING** rediction pundreds \mathbf{r} 502 the influencing (95) $\frac{0}{n}$ ore $\frac{0}{n}$ creep. $\ddot{\mathbf{o}}$ \mathbf{a} saseabs \overline{m} creep experiments $\frac{0}{n}$ conc ۲.
S creep, Following $\mathbf{\hat{p}}$ けのけの difficult and $\frac{1}{2}$ H.
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a 5 e $\frac{1}{k+1}$ $\frac{1}{2}$ **from** tai where loading creep -10 cient $\frac{0}{n}$ $\frac{1}{2}$ ateral $\ddot{}$ $\frac{0}{n}$ ujuzza concrete C_{t-1} $\mathbf{c}^{\mathbf{O}}$ $\ddot{}$ casting deero $c_{\mathbf{a}}^{\dagger}$ \mathbf{P}^* ia. e
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Q \mathbf{r} \ddot{a} $\ddot{\bullet}$ **ButAzp** Ω **Lama** decreases menb in orto H
J Shrinkage increases with Fig. $\frac{1}{2}$ produced $\frac{1}{3}$ and end. generally $2.1.8$ u₁ tw volume **Nith** ambient $\frac{0}{m}$ time CONCIECT \blacksquare the
b time shrinkage changes $\frac{1}{2} \frac{1}{2}$ considered dependent relative **Increase** similarly incre $\frac{1}{56}$ $\frac{1}{2}$ Dentined reaches $\frac{1}{9}$ humidity. ัด
ท carbonation volume \mathbf{r} n
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မ **u** \tilde{u} $\begin{array}{c} 2 \ 1 \ 1 \ 0 \end{array}$ $\ddot{}$ 5_o ι \blacksquare $\frac{1}{1}$ H_O for moist steam cured cured **CONCITER** concrete (2.22)

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H factors have humidity, conditions content shrinkage ., muntnim A which difer reppe the in. or less value ctively. thickcorrec- $\frac{0}{12}$

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81z $\frac{1}{9}$ ٣ŋ minim **Khere** p. \mathbf{u} number **Content** ene Ħ 14.
80 thickness percent **the** of 94-1b sacks of in percent. ambient of fine in inches, relative aggregate by weight, cement per cu yd. \boldsymbol{u} is the slump in inches, humidity in percent, pup $\frac{0}{10}$ $\overline{\mathbf{z}}$ concrete. r
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G $\frac{1}{9}$ time strain **Same** $\begin{matrix} 1 \\ 0 \\ 1 \end{matrix}$ prism with time due to **bhe** 98 is subjected to $\frac{1}{2}$ strain can be derined **SULBAIN** n
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Iows \mathbf{b} time defined where, ca1 a cepe. strain ۱Q $\frac{1}{2}$ r.
M Eg. Ľ. $\pmb{\omega}$ Explicitly, time dependent **terms** $(2, 3)$, $\frac{1}{2}$ pue stress, i.e. function subscripts function for \mathbf{a} can u
U $(1 - 1)$ inverse _დ
დ computing and expressed $\overline{\mathbf{u}}$ function represent mechann
M $\frac{0}{n}$ $\frac{1}{2}$ **H**

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ອ $\ddot{}$ $\frac{1}{2}$ $\begin{smallmatrix} 1 & 0 \\ 1 & 0 \end{smallmatrix}$ $\frac{1}{3}$ $\pmb{\ast}$ $\frac{1}{2}$ $\frac{1}{2}$ tension $\frac{1}{2}$ compression $(2, 27)$ (2.26)

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O \circ and \overline{z} \mathbf{r} currently valid values $Q =$ have $\vec{\Omega}$ α used. $\frac{0}{4}$ time dependent variab Tes $\frac{1}{2}$

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|គ \mathbf{r} **lo** Temperature Changes

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በ only $\begin{matrix} 1 \\ 0 \end{matrix}$ ane artificial $\frac{1}{\alpha}$ n
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11 e n d ature concrete **follows.** cient where \mathbf{r} $\alpha(T)$ temperature emperature e
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ਭ discussed ξ **Camperature** account $\frac{1}{n}$ detail

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เท Load Reversal $\begin{array}{c} \n\mathbf{a} \\ \n\mathbf{b} \\ \n\mathbf{c} \n\end{array}$ Complete Stress-Strain Curve

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nodel **rt** loading Joad \mathbf{r} 一門の or wind load are history **Lide** $\frac{0}{10}$ and $\frac{1}{2}$ ammonts reloading **SLESS-SERIES** are accounted of dynamic not considered in this study. an
a \mathfrak{g} curve. Ior cyclic live $\frac{1}{2}$ load history Ŗ. loading **neven** simple under qons Iosd p. **Brd**
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thei $\tilde{=}$ **Dide** $2.8.$ 'n, peor $rac{1}{2}$ **The** study of prestressed concrete adors Ecllowing Blakeley reversal $\frac{0}{n}$ and 942 model suotidunsse **Park** lears reversal utilized (83) utilized aze H. sections made path $5h15$ \mathfrak{p} in ø study is ehis similar with cyclic o u c model. Steasawons nodel

 (2) **Tensile** failure as the initial tangent or cracking $\frac{0}{4}$ concrete **820028** ۳. $\frac{m}{n}$

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Aue suned Ω alle losing resistance 875588 $\left(\frac{4}{3} \right)$ \mathfrak{a} of the close **Once** again. crack ü concrete compression and reopen **But** e n d r.
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• $\overline{\mathbf{r}}$ stress-strathelationship reversal reversal $\frac{1}{6}$ puokeq) bnoved) 02 20) \blacksquare reversal reversal $\frac{0}{7}$ qaed) **uavel** \mathbf{r} 40 tension o
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0 Commi u ot p $\ddot{\mathbf{r}}$. In vary けけのの \mathbf{u} $\frac{1}{2}$ are computed data $\frac{1}{\alpha}$ **209.** with time, $\ddot{}$ 0 \mathbf{a} w, ultimate $\frac{1}{2}$ pun. not $\frac{H}{1}$ within $\begin{array}{c} 1 \ 1 \ 1 \ 0 \end{array}$ available, o z e \bullet ω the Ereri ∞ COMPIESSIVE day program いのく compressive $\frac{1}{2}$ on $\frac{11}{10}$ σ Then strain pi
11 Ä $\frac{0}{3}$ -109 the

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 (4) $\frac{1}{2}$ Maximum Initial tangent tensile modulus stres \overline{u} $\frac{1}{2}$ $\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$ \mathbb{H}^2 \mathfrak{g} $\frac{1}{3}$ computed computed $\frac{1}{2}$ $\frac{1}{2}$ $\frac{n}{2}$ $54.$ (2.16)

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D da₁s a re **Once** determined, H.
M **the** defined values **the** $\frac{0}{10}$ $\frac{1}{2}$ Eq. (2.30) E_{C} , E_{L} , stress-strain \mathbb{E}_{1} , \mathfrak{a} ຕ
ດ (2.2) relationship and $\mathfrak{c}^{\mathfrak{a}}$ n
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 574 ACI tion \mathbf{r} $\frac{1}{2}$ perature tribution over the whole ither tory. ø Eqs through the zeriuts Shrinkage \bullet experimental ere
Bre (2.21) manner Specified strain \mathfrak{g} depth (2.24) may data and Increments $\frac{0}{n}$ a
T 70 structure and nonuniform eam frame temperature e a ch pu_d besu ed time $\frac{0}{m}$ particular shrinkage strain and temstep. element $rac{1}{2}$ histories n
De **Both** concrete can be shrinka $unifc$ are distribuspecified. specif \dot{a} pasn $\overline{\mathbf{H}}$ $\pmb{\Omega}$ $\frac{d}{1}$ s + stain $\frac{0}{7}$ Feq

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J chapter سا
ء $\frac{0}{10}$ concrete creep properties TITM ិ
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a Steel

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S \vec{r} generally are i ine iear **Surficient** \bullet $\frac{0}{10}$ **Phe** mode1 snyt reinforced properties specification which \mathbf{a} not define dependent on environmental conditions $\ddot{\bullet}$ concrete $\frac{0}{10}$ symmetrical reinforcing これる $\frac{0}{n}$ properties. structures. $\frac{1}{4}$ stress-strain anoqe steel, relevant origin, H unlike ehis relationship $\frac{1}{2}$ e
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տ only J $\frac{0}{n}$ r.
G $\bar{\mathbf{x}}$ non-mechanical strain considered $\begin{array}{c}\n\bullet \\
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Pa $\sum_{i=1}^{n}$ thermal strain different (2.5) The mechan- $\frac{0}{10}$ **Steel** e
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Pets \mathbf{u} **Writen** assumed same $E1g$. \mathbf{u} ື່ນ
ຜ **The 2.9.** ta
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 to stay within the envelope shown the stress-strain curve. adora EOIIOWS initial modulus, and the load reversal path is Four different material states of the Joad reversal path Their equations |--
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 $\tilde{=}$ In primary tension or compression

 \circ 葡 Ħ $\frac{1}{2}$ $\ddot{}$ \mathfrak{m} rt \blacksquare 면 (2.54)

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په the initial modulus $\frac{c}{d}$ \vec{c} yielding.

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M $(9^h - 5²0^h)$ the yield stress **Second** ा।
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En load reversal path

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 $\mathbf Q$ $\pmb{\ast}$ E_1 ($\epsilon^m - \epsilon^r$) Ń, ाग
ग \blacksquare \overrightarrow{u} (2.36)

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$\boldsymbol{\omega}$ $\ddot{}$ Prestre ۱ω $\frac{5}{15}$ Steel

 $\frac{a}{b}$ the curve subjected adopted ρ u
O نمو **811e STAGS-STATE** develops $\frac{5}{5}$ in. multilinear e u e \mathbf{a} Dentite puppeotund ifferent strength strength, $\boldsymbol{\varpi}$ H.
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H not EO KO \mathfrak{a}^{\dagger} prestreathed vield considered. CONQRESSIVE Erom $\pmb{\omega}$ e
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D stress-strain curve, r.
N curve gradually, and in the inelastic modulua. the
De large reached. reloading path plateau that stress-strain curve continues difference of reinforcing steel 1、他们的爱情。 Since H_OH **Also** پ
o \mathbf{r} accomodate prestrestng prestessing u
E temperature u" r.
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@ Fig. コロー ちけいゆめのーがわけかいけ 0
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Si $\frac{0}{1}$ **Steel** relaxation the decrease Relaxation theaturent **BLISS.** because steel, factor $\frac{0}{10}$ $\begin{array}{c}\n\bullet \\
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U $\frac{1}{4}$ $\frac{10}{10}$ $3Rg$ **SETESS** lust ene
e **increase BANDEB SHILL** time relaxation similarity another manifestation properties with time. dependent $\frac{1}{2}$ ب
80 time Fezai \vec{c} $\frac{0}{m}$ **BOIC** properties Relaxatio $\begin{array}{c}\n\bullet \\
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Su material where, time \bullet properties such r.
M dependent **ي** function strains, of space, V as tangent modulus, \mathfrak{a} is the number $\frac{1}{9}$ p. function **STRESS** $\frac{0}{2}$ concrete $\frac{0}{10}$ putAzea -TIEA IO lay-

 $V_{\mathbf{v}}$ $\phi \psi d\mathbf{v} = \sum_{i=1}^{n} V_{\mathbf{v}} \psi_{\mathbf{v}} d\mathbf{v} + \sum_{i=1}^{n} V_{\mathbf{v}} \psi_{\mathbf{v}} i d\mathbf{v}$ $(2, 37)$

 \mathbf{o} performed layer by layer element tegral involving varying material properties over the volume inforced concrete frame element perfectly \mathbf{H} ø frame Since stiffness matrix bended concrete and reinforcing steel are element, such together, o
Sa 0
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Si the displacement field of follows. internal the integral required is continuous. force vector, assumed to be Then any in-ሰ
0 can evaluate the
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a a c h r.
E reference tion varied material properties within a frame element, as shown inforcing 1514. u.
In layer $2.11.$ **assumed** piane are specified steel layers is chatucted in order the cross sectional area and distance Each concrete or steal layer in to be in a state of uniaxial stress, and for as geometric properties. a cross secto account Hom the m
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Friction properties of prestressing steel

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the Gaussian quadrature -15 length $\begin{bmatrix} 1 \\ 2 \end{bmatrix}$ $\frac{1}{3}$ $\frac{0}{r}$ the
b \mathbf{p} number Erame as explained $\frac{0}{m}$ element **S te 2** $\frac{1}{5}$ layers. performed by in chapter Integration $\frac{1}{2}$ three point along

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Da
O The composite action due Erames frame seructures bended element is discussed senuctures ij which the is assumed in
E in which the displacement detail \mathfrak{a} displacement to be prestressing ateel in chapter continuous, Eieit $\ddot{\cdot}$ distin- $\frac{1}{2}$ and unin connot
1 field

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 $\ddot{}$ MATHEMATICAL FORMULATION $\frac{1}{2}$ lo. **REEP**

$\ddot{\cdot}$ Review $\frac{0}{4}$ the Analytical Methods

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 Ω experiments a
D tional linear \mathbf{p} a
@ $\frac{1}{2}$ m ä te. veloped run about $\frac{1}{\Omega}$ time Various $\frac{1}{2}$ $\frac{1}{2}$ \mathbf{c}^* creep 0.411 e n e $\frac{1}{2}$ dependent $\frac{1}{9}$ $\frac{1}{2}$ \mathfrak{a} Net principle linear many analyti O, ሆ
ወ $(71, 72)$. **the** braid investigators. analysis Creep $\mathbf{\dot{o}}$ deezo al methods $\frac{0}{10}$ This assumption a
d uberposition law which \mathbf{c}^{\dagger} strain $\frac{0}{10}$ $\begin{array}{c}\n\bullet \\
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\bullet\n\end{array}$ concrete evaluating H
M compressive Most may **Deandrian** is denonstrated $\frac{0}{n}$ H.
M $\frac{\sigma}{\sigma}$ stutuoture these $\begin{matrix} 2 \\ 2 \\ 3 \\ 0 \end{matrix}$ defined valid \mathbf{r} **SASSA** e
D methods —
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S have H level the $\pmb{\omega}$ ट
र **Lak** $\frac{1}{2}$
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m \mathbf{f} and \bullet pliance importan $\pmb{\Phi}$ rt. α \blacksquare \blacksquare time **bine** rt $\ddot{\cdot}$ $\ddot{\cdot}$ 5 T d $\ddot{\mathbf{o}}$ けごにい \bullet $\frac{1}{2}$ anit rt **S** \mathbf{r} ັດ
ຄ peci $3.1.5$ $\frac{\mathbf{p}}{\mathbf{p}}$ aue **the** ific $\frac{1}{2}$ Eig. sustained \vec{c} \mathfrak{a} strain history **BNONS** benined \bullet $\mathbf{\omega}$ creep $\begin{array}{c} 2.16 \\ 2.17 \\ 2.18 \end{array}$ ant t unit a specific **BITSB80** $c(t)$ n
M sustained sustained stress applied **DIOKA** $\frac{1}{2}$ H.
M $\frac{0}{1}$ \bullet n
In total defined specific even curve $\hat{\mathbf{p}}$ strea applied ahown concrete SELESS 야
여 u. compliance the
b $E49.$ **Specimen** $\ddot{\cdot}$ produce Creap Specific $\frac{6}{1}$ on
Tr ai
Th ω curve, time **MITHALS Uime** subjectatain r.
M -0.0 $\frac{0}{m}$

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Ф u ึง $\hat{\mathbf{p}}$ ñ \mathbf{r} rt. $\ddot{\mathbf{0}}$ putsn \mathbf{a} egozies, hods. sented pproximate solution **Bazan** a uu s comprehensive The analytical \overline{r} namely and **HITH** purigure methods, Najjar かけの approximate (84) 1east a 1 m reviews methods assumptions. ta.
Sa anount ROSS methoda taken $\frac{0}{H}$ can he (95) available $\frac{0}{2}$ $\frac{1}{11}$ end
D and computational **The** classis.co findin **General** England effective line ۱ū an
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Q methods HORD. **bhe** $\frac{0}{10}$ rate concrete ζ Hore defining $\frac{0}{1}$ accurate creep erther $\frac{1}{2}$ method solutions in differential time mill dependent are
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m EOIIOWS. oldest aulus putsn uotinlos and simplest nethod, $\frac{1}{2}$ initainy eitective method. present $\frac{11}{11}$ sntnpou Ω pnsist $\frac{\omega}{\omega}$ ζ **in**

 $\overline{\mathbf{r}}$ $\frac{1}{1}$ $= 1/\bar{c}$ (t) こ・こ

where previously. $\frac{1}{6}$ $\frac{1}{8}$ Total strain c(t) $\frac{1}{9}$ specific compliance ր.
00 then o
rt computed time n
" $\frac{1}{2}$ Deriad

 (1) \blacksquare $\sigma(t)/E$ (t)

 $(2 - 5)$

which predicted afte 네
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decrease concrete **BILLE** Ñ $2.6,$ method $\frac{1}{10}$ **the** uot $\frac{0}{2}$ Into ζ |⊷
M initial loading are specific **QO68** eria true neglected. account. not method $\frac{\omega}{\omega}$ **BUDDED** compliance take Thus, $\frac{1}{2}$ **Also the** H
H $\begin{array}{c}\n\uparrow \\
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0\n\end{array}$ E_{Id} complete **Btrains Overestimated** はいけのはな with aging, **BURGSS** い
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histories due to $\frac{1}{10}$ strain reduced $\begin{array}{c} \mathbf{0} \\ \mathbf{0} \end{array}$ becanse なわれの好物 recovery is **Ahona** end
D $\mathbf{r}^{\mathsf{t}}_{\mathsf{0}}$ pates ր
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U zero, $\frac{0}{1}$

since \mathbf{H} A unction **Baed The** $\frac{1}{2}$ loading. $\frac{0}{10}$ **Phe** rate the assumption $\frac{0}{10}$ Specifically current creep method, due that いけいのめ e ne $\begin{array}{c} Q \\ Q \\ Q \end{array}$ creep to Glanville a
Da stzain the
O eure **Fate** (18) elaps H.
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ທ \bullet $\pmb{\mathsf{p}}$ Ω,

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 $\frac{dE^c(t)}{dt}$ $\frac{\mathbf{p}}{\mathbf{p}}$ \mathbf{H} $\frac{d}{dz}$ (t) $\frac{d}{dz}$ (t) $\frac{d}{dz}$ $(5 \cdot 5)$

 $\begin{pmatrix} \mathcal{L}^{(2)} & \mathcal{L}^{(1)} & \mathcal{L}^{(2)} \\ \mathcal{L}^{(1)} & \mathcal{L}^{(2)} & \mathcal{L}^{(2)} \end{pmatrix}$

evaluated by the integration, Ereke c(t) is the specific creep. Then ch
D creep strain ب
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 $\epsilon^c(t) = \frac{1}{2}\sigma(x) \frac{dc(x)}{dx} dx$ dx $(1 + E)$

strain history, thus no creep recovery is accounted for. effect on creep strain is disregarded. varying stressess with time is included, but the history This method does not include the effects of aqing and

PHS law, stress with total stess produced strain is expressed in terms In the differential formulation of the linear linear differential operator, Creap $\frac{0}{10}$

$$
\varepsilon^{G}(t) = \frac{\alpha_{n}D^{n} + \alpha_{n-1}D^{n-1} + \cdots + \alpha_{0}}{\beta_{m}D^{m} + \beta_{m-1}D^{m-1} + \cdots + \beta_{0}} G(t)
$$
\n(3.5)

 $\frac{0}{n}$ Zienkiewicz (88) expressed the creep strain with a series instantaneous elastic strain from the total strain, where, D is a differential operator, d/dt. partial fractions obtained from the expansion of Eq. (3.5) Separating the

 $\epsilon^{c}(t) = \frac{n}{1 + \epsilon_1} \frac{a_1}{b_1 + b_2} \sigma(t)$ (3.6)

e u a Ù, determination of the coefficients a_i and b_i which may repre-Xelvin elementa. はこせい ent. r
M
O can be interpreted as a response of a series of n the effects of aging and temperature variations restrict $\frac{0}{1}$ this method for concrete. But, difficulties in the experimental **Sarne** (37) used eruis

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क्षे $\pmb{\mathfrak{a}}$ H. rŧ NUOLUTUR $n + s$ thre. $\pmb{\sigma}$ dimensiona سأ time a
O pendent analysis

 H_1 \vec{c} \mathbf{C} $\overline{\mathbf{u}}$ $\mathbf{r}^{\mathbf{t}}$ Lanoito $\pmb{\Omega}$ ju. H \mathbf{G} Fres the
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თ \overline{u} formulation urszis r.
n represented $\frac{0}{12}$ $\begin{array}{c}\n1 \\
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Ci $\frac{\mathbf{p}}{\mathbf{N}}$ œ Ω н Volterra $\mathbf 0$ \bullet U \overline{a} $\frac{1}{2}$ ÷. $\frac{1}{2}$

$$
\sigma(t) = \frac{t}{\delta} \frac{1}{\sigma(\tau, t - \tau)} \frac{\partial \sigma(\tau)}{\partial \tau} dt
$$
 (3.7)

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a q A \blacktriangleright instant compliance $\frac{1}{2}$ \mathbf{u} 791 the й
Ф loading, Ω ODSSTATION THE aneous $\binom{1}{2}$ $\frac{1}{1}$ $5(1, 1-1)$ elastic \vec{r} $\frac{1}{2}$ $\frac{1}{\alpha}$ the けいの **Can** part specific o
O a B e after and divided $\frac{0}{10}$ casting $\pmb{\omega}$ concrete compliance creep part into $\frac{0}{2}$)
(수 **CAS** concret a
fi loading $\mathbf{\dot{\sigma}}$ **arts** time $\ddot{\bullet}$ \bullet ۰. v, $(1 - 1)$ a n ads
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 (1, 1 - 1) = $\frac{1}{12}$ + C(1, 1 - 1) (3, 8)

Εq. \overline{C} a he p. \mathbf{H} \mathbf{u} $\hat{\omega}$ \bullet $\frac{1}{2}$ (1) E e h e can specifi $\frac{1}{2}$ $\frac{1}{9}$ PU₇ Ω rewritten, sulubom $\frac{0}{5}$ $\ddot{\bullet}$ pi
rt $\frac{0}{10}$ \mathbf{r}^{\dagger} ime elasticity $(1 - 1)$ **BELer** pi
ft a 6 a loading ٣Ì, \bullet and
D \bullet $\frac{1}{1}$ Lhen, $\frac{1}{4}$

$$
e^{\sigma(t)} = \frac{1}{E} \left[\frac{1}{E(1)} + c(t, t - \tau) \right] \frac{\partial \sigma}{\partial t} dt
$$
 (3.9)

5 T d **bhe** Ω implies Ω $\pmb{\omega}$ adns $\frac{1}{2}$ \bar{a} $atial$ pəsi \mathbf{D} strain rposition method. سه
د given 'n H ζ $\tilde{\mathbf{N}}$ \circ m
O that H ua iw Ω the SSSSSSS \vec{r} time histories \boldsymbol{u} $\boldsymbol{\omega}$ $\frac{0}{H}$ a
D linear ach can arts **Axially** SETES with a
G $\boldsymbol{\mathsf{u}}$ superposition caused \pmb{u} cbtained by history Fhis method different $\frac{1}{9}$ loaded ζ independent peher are
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b not $\frac{q}{4}$ the
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U **rt** $\mathbf{5}$ n $\overline{\mathbf{r}}$

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McHenry (68) o y a **HARTH** pezilized $\begin{array}{c}\n\uparrow \\
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The the experimental $\frac{1}{9}$ FOT Specific function. creep c(t,t-t) has **bhe** numerical procedure for the solution of mich Eunction numerical evaluation of the function offen influences creep Proper choice da La also $\frac{1}{8}$ in a
B as closely very important to be approximated by some \mathfrak{g} of the analytical function for the ប
ល selected such as possible 0
m deero in creep analysis because strain, the efficiency of that Eq. analytical the
B in
11 $(5:1:3)$ **H115** specific けいの

$$
c(t) = \begin{cases} c(t, t - t) \frac{\partial \sigma(t)}{\partial t} & (1, t - t) \\ c(t, t - t) \frac{\partial \sigma(t)}{\partial t} & (1, t - t) \end{cases}
$$

M

$$
\varepsilon_3(t) = \varepsilon_1(t) + \varepsilon_2(t)
$$
\n
$$
\text{From Eq. (3.9), case, a-train } \varepsilon^c(t) \text{ may be written}
$$

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superposing $\epsilon_1(t)$ and $\epsilon_2(t)$ as shown rhen the strain history $\epsilon_3(t)$ due \vec{c} $\sigma_{3}^{(t)}$ in Fig. $\frac{1}{2}$ $3.2.5$ obtained ă

 (11.1)

 $\epsilon_2(t) =$

 ϵ_2 (t) due to $G_2(t)$ is

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 $E_1(t) = 0$

 \bar{c} (t₁, t-t₁)

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tory $\epsilon_1(t)$ due to $\sigma_1(t)$

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stress history o₃ (t) shown in Fig.

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by superposing $\sigma_1(t)$ in which

 $-a \leq (t_2, t-t_2)$

 \overline{a}

principle m ollowing form For the tion
T concrete the
 specific creep analysis, suggested creep function. 114

 Ω $(1, 1, 1, 1)$ $\overline{\mathbf{p}}$ $+$ [1-4) $(1-4)$ βe^{-pT} $(1-e^{-m(t-T)})$ (3.14)

mental where a, B, Y, P, data. \blacksquare DH TO parameters pasn \mathfrak{a} m
H
H **bhe** experi-

Arutyunyan (90) suggested the Eorm

 Ω $(7, 5 - 1)$ $(a+b/7)$ E B_ke Y_k (t-1)
 $\sum_{k=0}^{m} B_k e^{-Y}$ $(3:12)$

experimental data. **Shere** $\frac{1}{2}$ b , B_k , Y_k , Ħ are coaficients m
O
H fitting **bhe**

dependent Selna (44,45) analysis proposed the following $\frac{0}{15}$ reinforced concrete form in frames. his
B time

 Ω $(7 - 5 - 7)$ $=\sum_{\substack{1\\ \pm\,m\,\neq\,j\,\neq\,1}}^4\alpha_{\pm}\,\alpha_{\pm}\,\alpha_{\pm}\,\alpha_{\pm}^{-1}\tau^{-0}\,,\,\, (j\!-\!2)\,\left[\,\,\uparrow\, -\,e^{-K}\,\downarrow\,\left(\,\uparrow\, -\,7\,\right)\,\right]$ (31.10)

 $\frac{1}{2}$ \circ scanlon total strain is determined from the quantities stored from experimental where H eura. previous Mukaddam and α_1 , K_1 , dependent pasn (86) time data. a
are
ere steps instead of the entire history. Bresler deflection of reinforced Selna's formulation of creep for his In Selha's creep coefficients (91) proposed ተ
0 D.
W formulation, current p. determined specific concrete slabs. Creep uozy study

 Ω

variations function in which the iple. are taken **HRto** effects of both age account with $\frac{1}{9}$ and
B time-shift temperature prin-

 $c(7, t-t+T)$ \bullet ֓֕׆֧
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֩֩֩֩

 (11.11)

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consists $\frac{0}{1}$ three components

ON D pasn $\frac{1}{2}$ **IOI** Total stress this formulation. produced strain e^o (t) $\frac{a}{11}$ kue time ct

a ô e H_O えんけい and 竹口の an u integral formulation which takes into evaluation of creep strain at any time is developed temperature variations. the present study an efficient numerical procedure eur following **BCCOUNT** assumptions **Doth**

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N Age e
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D
D Temperature Dependent Integral **Formulation**

 $\frac{0}{2}$

Creep

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پا that the storage of only a vector and the stess increment pusind parameters n, p_i are determined from experimental data. azena a time step immediately preceding the current required to evaluate the creep strain increment and temperature dependent function the p. this
t age and temperature dependent function C₁ (T,T) and HOTH OWN THE pd they did not suggest a specific specific creep function, they showed C_1 (7, 7) C_2 HONE OF DOUD **Sine** 無理 step tury ζ

HORBVEY age shift function. data, estricted to oly is the the application of their formulation of a_1, λ_1 relatively simple structures a z e temperature coefficients shift determined function because all and
D HOH Creep (1) \uparrow experimental ter
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rent atrains.

Zienkiewicz and Watson (92) proposed to use

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 (3.18)

 $(7, 6+7, T) = \frac{n}{4}$ C₁ (7, T) [1-e ^{-p}₁ (t-t)

previous

Stress

histories have to be stored

to evaluate

n)
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 $\frac{1}{\alpha}$ $\frac{1}{2}$ \mathbf{u} ϵ^m (t) $\ddot{}$ ϵ^{a} (t) $\ddot{}$ (4) 2^5

T.
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-Each 2.1, and expressed xith component illustated in Fig. $\frac{0}{n}$ a superposition the strain has been $2 + 1 + 5$ integral defined Creep atzain ti. acct 6° (t) i
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S
S

 $\frac{1}{2}$ \blacksquare $O - d$ $\frac{18}{9}$ (1, t-1, 1) $\frac{30}{9}$ (1) $\frac{1}{9}$ $(3 - 20)$

m,

Eq. r.
D applied deero **Which** (3.20) $\binom{2}{2}$ function dependent on age **WITHOWS** the kernel function c (t, t-r, is Creep is used both strain is assumed to be proportional both in tension in compression and tension. and and compression. temperature the
e apecific variations. And त
0

mith n
4 **HO** deerd eny けいの different durations of $\tilde{\epsilon}$ strains produced by stress time evaluation of creep Principle of superposition is assumed to be \mathbf{r} can be obtained time stzain. e
D changes at $\frac{1}{5}$ the sum of \boldsymbol{c} Thus, rt
" total different ages independent Creep pilsv strain

n d
U **This** material time auch Eixed ature almple shifted that relationship curves $\left(\frac{4}{3} \right)$ variation, as illustrated in Fig. 3.3. reference material (91). which obeys the \ddot{r} Concrete is assumed \checkmark horizontally with at temperatures $\begin{smallmatrix} 1\\0\\1\end{smallmatrix}$ temperature, can be written The specific such a time-shift T₀and pue \mathfrak{a} \mathbf{a} material is creep versus distance Ą be a thermorneologically \ddot{H} \mathbf{p} are principle constant identical $\frac{1}{2}$ (L) $\frac{1}{2}$ defined logarithmic m
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H temperature $\frac{1}{6}$ $\frac{1}{2}$ $\frac{1}{2}$ Po De 0
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0 shape temper- \mathbf{p}

 c_T ($ln t$) $\ddot{}$ c_T (ℓ nt $\ddot{}$ (1) \uparrow

 $(3 - 21)$

 (3.19)

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 \mathbf{D} represent \mathbf{H} winere arguments kn k an d $\ddot{}$ $c_{\texttt{T}}$ \mathbf{r}_0 (1) \uparrow respectively. けいの $\frac{0}{3}$ $G_{\mathbf{b}}$ $\pmb{\mathfrak{g}}$ both sides same curve, taking the ia
14 $t e^{\psi(\mathbf{T})}$, o
P
D specific and Since noting both sides creep curves that e^{2nt} exponential $\frac{0}{1}$ the Eor $\pmb{\mathbb{R}}$ σ equation temperature and of the

 Ω \mathbf{r} (t) \mathbf{u} $c_{\texttt{T}_0}(\texttt{te}^{\psi(\hat{\mathbf{r}})}):=$ c_T (t ϕ (T)) ; ϕ (T) \mathbf{u} $e^{\psi(\tau)}$ (3.22)

 \mathbf{r} ρ, Mukaddam **In** н trie-enter specific where $\frac{1}{n}$ \overline{a} annant $\frac{1}{\sigma}$ \bar{r} p. lacing the obtained ϕ (T) is (66) reference temperature To. and
B eazno deezo the principle **Bresler** time t by Ross, et called (16) for concrete was demonstrated by for any temperature T is obtained by a temperature shift by t.o(T) in al (76,71), Browne using temperature the specific The validity function. dependent t93), and creep $\frac{0}{10}$ $5h15$ Then the curve creep

m And, $\pmb{\Omega}$ Ω ome $1.8₀$ uring that interval. Inct H
OH e u H \overline{G} time **the** interval, the **Stress** calculation **ateps** changes $\begin{array}{c}\n\mathbf{r} \\
\mathbf{r} \\
\mathbf{r}\n\end{array}$ stress $\frac{0}{n}$ E
E **M 76** creep 1,2,".N (see assumed to is assumed strain increment occur ታ
ዕ section remain only $\frac{\omega}{\tau}$ $2.2.1)$ Butznp constant

pecific **Hhe** creep following form Eunction is used in this study. $\frac{0}{10}$ a G
0 and temperature dependent

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 Ω $(7, 5-7, T)$ $\sum_{i=1}^{n} a_i(t)$ [1-e $\lambda_1 \phi(T)$ (t-T)
 $\lim_{i \to 1}$ (3.2)

 Ξ $\frac{1}{2}$ ental which m, a_i(t), λ_{\pm} , ϕ (T) are n
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time **PINDA** considerable creep previous stress increments $\frac{0}{m}$ And **ateps** ្នុង **Che** 707 require strain t_n , and t_n (3.26) to creep ø computer difficulty increment \mathbf{p} **Btain** substantial storage $(32 - 28)$ is obtained by Eq. (3.26). even for increment at any time step. $\frac{1}{4}$ $\frac{1}{n}$ かけの computational is evident moderately **A_en**
Ae peatnbez penrring space that **Sized** \mathfrak{a} procedures, and **This** knowledge evaluate gurrup computational problem On inspection **Presents** the
B time and $\frac{0}{10}$ Ø **a11** p $\frac{H}{D}$

 $\begin{smallmatrix}&&0\\&&1\\1&&0\\1&&0\end{smallmatrix}$ $\ddot{}$ $\Delta\sigma_1$ * c (t₁ * t₁ * t₁ * T) + $\Delta\sigma_2$ * c (t₂ * t_{n+1} + t₂ * T) (3.28)

Total creep ntair $\begin{bmatrix} 1 \\ 2 \\ 0 \end{bmatrix}$ $\frac{1}{\Omega}$ time step $\begin{array}{c}\n1 \\
1\n\end{array}$ can o
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+ \cdot \cdot \cdot + \circ_{D_{n-1}} \cdot \circ_{C_{n-1}} \cdot \circ_{D_{n-1}} \cdot \circ_{
$$

$$
\varepsilon_{n}^{2} = \Delta \sigma_{1} \cdot c \left(\varepsilon_{1} , \varepsilon_{n} - \varepsilon_{1} , \tau_{1} \right) + \Delta \sigma_{2} \cdot c \left(\varepsilon_{2} , \varepsilon_{n} - \varepsilon_{2} , \tau_{1} \right) \tag{3.27}
$$

$$
\begin{array}{c}\n\mathbf{a} & \mathbf{b} \\
\mathbf{b} & \mathbf{c} \\
\mathbf{c} & \mathbf{d} \\
\mathbf{c} & \mathbf{d} \\
\mathbf{d} & \mathbf
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\begin{array}{c}\n\bullet \\
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 $\begin{bmatrix} 0 \\ 1 \\ -1 \\ 0 \end{bmatrix}$

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 $\mathfrak{m}^{\mathfrak{g}}_{\mathfrak{g}}$

 $\binom{u_{1}}{1}$

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 $(1 - u_1)$

 (3.26)

 $\mathfrak{p}^{\mathsf{c}}$ n

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 $\begin{smallmatrix} 2 \\ 3 \\ 1 \end{smallmatrix}$

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 $\sigma\left(\tau_n\right)$

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 $\sigma(t_{n-1})$

 (3.25)

 (3.24)

used.

 $P_{\rm n}$

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Aac ting Eq. (3.30) from Then \mathbf{r} t. where \bullet $\frac{5}{3}$ $\frac{1}{2}$ taking the temperature history into account. specifie ITTM Ω imilarly Eq. (3.28) may be written Ω $n-1$ = $\Delta\sigma_{\frac{1}{2}}\Sigma a_{\frac{1}{2}}(t_{1})$ (1-e Þ Þ $\ddot{}$ \blacklozenge $\ddot{}$ $\pmb{\parallel}$ ene
e form ef (3.5) \blacksquare Eq.
be shown that sumnation is made on i $\ddot{}$ \blacklozenge \bullet $\Delta\sigma_{\textbf{n}-1}\Sigma\mathbf{a}_{\pm}\left(\mathbf{t}_{\textbf{n}-1}\right)\left(1-\mathbf{e}^{-\lambda_{\pm}\phi\left(\mathbf{T}_{\textbf{n}-1}\right)\Delta\mathbf{t}_{\textbf{n}}}\right)$ $\Delta\sigma_{1}^{\dagger}\Sigma a_{1}^{\dagger}$ (t₁) [1-e] $\begin{array}{c}\n\bullet \\
\bullet \\
\bullet\n\end{array}$ Ad₂Za₁(t₂).[1-e $\Delta\sigma_{i} \Sigma a_{\underline{i}} (t_{i}) e^{-\lambda_{\underline{i}} (\phi (T_{i})) \Delta t_{2} + \cdot \cdot \cdot \phi (T_{n-2}) \Delta t_{n-1})}$ $\Delta \sigma_{\mathbf{n}-2} \Sigma$ ai (t_{n-2}) [1-e
-^{λ i (1-e
- λ i (1-e} $\Delta \sigma_2 \Sigma a_{\frac{1}{2}} \left(\begin{matrix} t_{2} \end{matrix} \right) \left[1 - e^{-\lambda_{\frac{1}{2}}} \left(\phi(\Upsilon_2) \Delta t_{3} + \phi(\Upsilon_3) \Delta t_{4} + \cdots + \phi(\Upsilon_{n-2}) \Delta t_{n-1} \right) \right.$ $\ddot{\cdot}$ creep strain increment As^c_n is obtained by (3.27) creep function expression given in Eq. the
B can be specific this - ^ i (φ(r₂) Δt₅+φ(r₃) Δt₄+ · · · +φ(r_{n-1}) Δt_n) - λ <u>ι</u> (φ (τ ₁) Δτ ₂ + φ (τ ₂) Δτ ₃ + • • • • + φ (τ _n – 1) Δτ _n) Eq. (3.29). -> 1 (+ (r 1) A t 2 + + (r 2) A t 3 + - - - + + 0 (r a - 2) A t n - 1) written difficulty creep $= 1, 2, ...$ a
B function expressed follows substriting can a
L avoided $\begin{array}{c} -1 \\ -1 \\ 0 \end{array}$ (3.23) and $\frac{1}{2}$ ट
४ $-\lambda$ _i ϕ (T_n - i⁾ Δ t_n anptzacputsn $(0.5 - 30)$ $(5:2)$ $\frac{1}{2}$

 \ddotmark $\Delta \sigma_2 \Sigma a_{\pm}$ (t₂)e
 $\Delta \sigma_2 \Sigma a_{\pm}$ (t₂)e
 $\Delta \sigma_1$ (t₂)e $-\lambda \pm \phi (T_{n-1}) \Delta t_{n}$

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$$
A_{1,n} = A_{1,n-1} \cdot e^{-\lambda \frac{1}{4} \phi \left(T_{n-2} \right) \Delta t_{n-1}} + \Delta \sigma_{n-1} a_{1} (t_{n-1}) \qquad (3.35)
$$

\n
$$
A_{1,2} = \Delta \sigma_{1} a_{1} (t_{1}) \qquad (4.36)
$$

 $\begin{array}{c} 0 \\ 0 \\ 0 \end{array}$ expression which enables Inspection value h_1 , $n-1$ of Eq. successively. (3.33) us to evaluate and (3.34) leads $A_{\frac{1}{2}}$, n $\frac{1}{2}$ \vec{c} szom the the de following previ-

$$
+ \ \ \delta \sigma_{n-2} a_{i} (t_{n-2})
$$
 (3.34)

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$$
1, n+1 \quad \text{for } i < 1
$$
\n
$$
-\lambda_{\frac{1}{2}} \left(\phi \left(T_{2} \right) \Delta t_{3} + \phi \left(T_{3} \right) \Delta t_{4} + \cdots + \phi \left(T_{n-3} \right) \Delta t_{n-2} \right)
$$
\n
$$
+ \Delta \sigma_{2} a_{\frac{1}{2}} \left(t_{2} \right) e^{-\lambda t_{1}}
$$

$$
\begin{array}{lllll} \text{Jation} & \text{the general description of } A_1, n, & \text{we note that} \\ \text{a. } a_1 & = & \text{log} \left(t_1 \right) e & \text{a.} \\ \text{a. } a_2 & (t_1) e & \text{a.} \end{array}
$$

$$
4 \text{ log}_{n-2}a_{\frac{1}{2}}(t_{n-2})e^{-\lambda_{\frac{1}{2}}}\phi(T_{n-2})\Delta t_{n-1} + \Delta\sigma_{n-1}a_{\frac{1}{2}}(t_{n-1}) \quad (3.33)
$$

$$
-\lambda \oint_{\mathcal{L}} \Delta \sigma_{\perp} \quad \text{as} \quad (\tau_{\perp} \quad \text{a}) \quad \rho_{\perp} \quad \text{and} \quad \tau_{\perp} \quad \text{for} \quad \tau_{\perp} \quad \text{as} \quad (t_{\perp} \quad \text{a}) \quad (3.3)
$$

$$
-\lambda_{\frac{1}{2}}\phi(T_{m-2})\Delta t_{m-1} + \Delta\sigma (T_{m-2})\Delta t_{m-1} + \Delta\sigma (t-1) \quad (3.3)
$$

$$
-\lambda \cdot \theta \cdot (T - \lambda K)
$$

$$
\frac{1}{2} \sum_{i=1}^{n} \frac{1}{2} \sum_{i=
$$

$$
\frac{1}{2} \int_{0}^{\infty} \frac{1}{2} \cos \left(\frac{1}{2} \cos \left
$$

$$
\Delta \sigma_1 a_1 (t_1) e^{-\lambda_1} (\phi(T_1) \Delta t_2 + \phi(T_2) \Delta t_3 + \cdots + \phi(T_{n-2}) \Delta t_{n-1})
$$

$$
- \lambda_1 (b(T_1) \Delta t_1 + \phi(T_1) \Delta t_2 + \cdots + \phi(T_{n-1}) \Delta t
$$

 $\mathbf{A}_{\hat{\mathbf{1}}}$, \mathbf{n}

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where

 $\mathbf{A}_{\hat{\mathbf{1}}}$, \mathbf{n}

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 $A_{\frac{1}{2},n}$ [1+e

 $-\lambda$ _i ϕ (τ _{n-1}) Δt _{n</sup>]}

 (3.2)

$$
x = \frac{1}{2} \left(\phi \left(7 \right) \right) \phi + \frac{1}{2} \phi \left(7 \right) \phi + \frac{1}{2} \phi \left(7 \right) \phi + \frac{1}{2} \phi \left(7 \right) \phi \left(7 \right) \phi
$$

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$$
\Delta \sigma_{n-1} \Sigma a_i (t_{n-1}) [1 - e^{-\lambda_1} \phi (T_{n-1}) \Delta t_n]
$$
 (3.31)

 $\frac{5}{3}$ $(3, 3, 1)$ can be simply written

 $\ddot{}$

 $\boldsymbol{+}$

 $\Delta \sigma_{n-2} \bar{\Sigma} a_{i} (t_{n-2}) e$

 $-\lambda \pm \phi (T_{n-2}) \Delta t_{n-1}$

 $\begin{bmatrix} 1 \\ -1 \end{bmatrix}$

 $-\lambda \pm \phi$ (T_n - 1⁾ Δ t_n

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In u analyze \mathbf{r} m C) t. $\frac{0}{n}$ $\frac{1}{\pi}$ evaluate $\ddot{\mathbf{o}}$ ormulations pace \overline{r} $\frac{1}{10}$ $\frac{1}{10}$ ö ation only Ō. note ā. to. and \bullet have Ëħ, $\Delta \sigma_{n-1}$ complex that, $\frac{0}{n}$ the
u **the** computational $\frac{1}{3}$ creep u
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ឲ which concrete butsn $A_1, n-1$ **DROTOD** saves strain part Eq. time ÷ $\pmb{\mathsf{D}}$ 원
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0\n\end{array}$ line. calculation $\tilde{\mathbf{z}}$ actual an calculated $\frac{1}{2}$ stress deep appropriate SCASS. $\frac{0}{4}$ law would is obtained ξ the
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 $\frac{0}{h}$ cussed by Fröberg (95) using Prony's method in which solutions where x = t-1 representes the time elapsed since the age T. mth degree polynomial equation and systems $\frac{0}{2}$ simultaneloading

c(x) = $\sum_{i=1}^{m} a_i (1-e^{-\lambda_i}x)$ (3.41)

by Eq. (3.23) are determined from experimental creep function in Eq. (3.23) assume that parameter m is known. at some loading age t and reference temperature T₀. shift function $\phi(T)$ in the specific creep function expressed can be written Then the specific hnd daazo **DBCB**

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4 Determination of Specific Creep Coeficients

Becker and Bresler used the values of c, = Roll (71,72). 0.465 a1.80 rd and r2 and r2 = 1.800.0 **Desed** $\frac{0}{3}$ 2.33 and the study 0
|
|| $\frac{0}{10}$ $\ddot{}$

can be (3.40)

 $\frac{12-1}{12-2x}$ = 15 $1 \circ 2 = 1 \circ 2 = 1$

calculated from the three equations given above.

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With given values of

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 z_2 , c₁

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 $\begin{array}{c} \frac{1}{2} \\ \frac{1}{2} \\ 0 \end{array}$

 (3.5)

 (3.38)

 $(3, 37)$

 $\begin{matrix} 0 \\ 0 \end{matrix}$

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C enables pecific þ٠. $\mathbf{\hat{r}}$ comparing the line e e a $\frac{1}{9}$ $\frac{1}{2}$ creep found that the to fit equations function with results obtained using different the experimental creep are
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m following fixed values butsn Ag **data** degree this \mathfrak{a}^{\dagger} $\frac{0}{10}$ ene
9 method values accuracy. bemusss $\frac{0}{n}$

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 \exists $\pmb{\mathfrak{q}}$ $\frac{1}{2}$ \mathbb{R}^2 $\pmb{\parallel}$ 10^{-7} $\ddot{}$ μ. \mathfrak{a} $1, 2, 3$. $3.42)$

 $\begin{matrix} \mathbf{p} \\ \mathbf{r} \\ \mathbf{r} \end{matrix}$ \ddot{z} , \ddot{z} **bhe** ene けいほゆ time, Then, \bullet experimental creep data are given at discrete \dot{z} determination of a_i ; $\frac{1}{2}$ ean be 00
0 ن
م in and that we have N pairs of the value any given loading which y_j determined by setting up the following N is the total number $\frac{1}{2}$ tra
a \mathbf{r} experimental specific age and reference $= 1, 2, 3$ of time **BIS** rednired. $F(t)$ ($F(t)$ $F(x)$) steps. temperature creap points equations. Then the asoddns ू
ग \mathbf{r} u
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 $\frac{3}{2}$ a_i (1-e ^{-10</sub>⁻¹x¹) =} ÷ \overline{u} \blacksquare $1, 2, 7, 9$

ί. These coefficients (3.43) equations are solved by the least-square represent a₁, a₂ and a₃ **N 8602** in which N is much larger $\frac{0}{n}$ linear equations method (95, H $\hat{\boldsymbol{\omega}}$ than unknown ့
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 \mathbf{r} (3.43)

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U least-square section prepuera data is available $2.2.2$ values method yan ರ
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respectively. **SHOIP** 1011 (1) E **This** $\frac{9}{10}$ equation may initial moduli **BISD** $\frac{a}{\tau}$ ben ed pading r.
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(1) is $\pmb{\mathsf{N}}$ ai($\frac{1}{10}$) . $\frac{1}{2}$ ($\frac{1}{10}$) . $\frac{1}{2}$ ($\frac{1}{10}$) . $\frac{1}{2}$ \vec{o} $\ddot{}$ \mathbf{P}^{\perp} $\pmb{\parallel}$ $1, 2, 3$ (3.44)

 $\frac{0}{\Omega}$ aze EOIIONS **SORe** $\tilde{\mathbf{c}}$ cient constant Creep only Ω $\frac{0}{4}$ φ $\frac{1}{6}$ $(1)^{\frac{1}{3}}$ e laentical \mathbf{H} loading age H
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H icients \blacktriangleright $\mathfrak{c}_{\mathfrak{a}}^{\mathfrak{a}}$ curves \blacksquare and (2.20). for moist $\sum_{n=1}^{\infty}$ phying $\frac{0}{2}$ for different loading ages can H
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H n
S S C H_O \mathbf{u} loading any except the $\frac{1}{2}$ σ ⁺ Drumbrent cured other ζ AC1 $0 + 70$ rhus, $\frac{1}{2}$ ade
a $\begin{array}{c}\n\bullet \\
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\bullet\n\end{array}$ Eactor creep determined by concrete loading age the loading because the least-square **Butwhee** loading E_{C} data, **from** The ET_e tion
to $11e$ \vec{A} age, **ACI** ultimate $Eq.$ the
o **Van** method $\frac{1}{2}$ determina $\frac{1}{\alpha}$ DHHMMM equations least-square once ρ, (2.20) computed pther may determined Creep $(0,1)$ is only tion conditions ិ
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approximated tion **Unazent** plotting $rac{1}{2}$ **Dhe** specific creep temperature $\frac{0}{7}$ temperatures $\frac{1}{2}$ rt
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ب temperature polynomial **Shiffs** ρ
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\bullet\n\end{array}$ $\frac{0}{10}$ creep present specific discrepancy experimental creep ages can be BIOWNO18 curves genezated between (55) はののご experimental ONGOD rt
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4. **SOLTION** STRATEGY FOR EHE **INE** DEPENDENT

NONLINEAR PRAME PROBIEN

$\frac{1}{2}$ problem Statement

time CQ reactions, pue $\frac{1}{2}$ Then curve formulation Distributed tanzexe diven Ioads assembla nwohs しいののの $\frac{0}{n}$ shrinkage $\frac{1}{2}$ Suppose every either H. prist poundary want ۵
۵ $E\ddot{z}$ $\frac{0}{10}$ **Ioads** $\frac{0}{10}$ internal Part loads may be converted into equivalent (2) . every part of e
M to find out ά 医原 characteristecs Einite $4.1.4.$ are
a any instant conditions きゅうた ehe of the structure and the The joint asumed consistent Eorces to analyze elements Ehe joint the structure e
8 structure \mathfrak{a} $\frac{0}{n}$ HO
N load history, unous $\frac{0}{n}$ ប
® interconnected time **each** displacements, load method ø the concrete applied only planar **aze** in Fig. H.
M element, given. ideaiized a
m concrete stress-stain temperature histo-<u>០</u>
អ Vns $4.2.5.$ stuioi yd strains $\frac{a}{n}$ 916 Ŵ, anpport instant **Also** Iumped joints u
S given. frame joint **The** 9
U Creap and $\frac{0}{n}$ そいけい

noniinear \overline{z} $\begin{array}{c} 1 \\ 1 \end{array}$ **The** Fhe because strain-displacement stress-strain $\frac{0}{r}$ a u q large $(c - \epsilon^m)$ displacement effects. $(\frac{2}{3}-3)$ relationship relationship $\frac{1}{\alpha}$ nonline t.
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time ζ which \mathbb{H}^1 inter $\frac{1}{6}$ added α domain. vals n due increments \mathfrak{a} $\ddot{}$ time and ene $\hat{\mathbf{p}}$ domain previous step $\frac{0}{m}$ displacements forward integration r.
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ທ into $\frac{1}{3}$ and march ω surezas discrete r.
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a equilibrium analysis \geq nor
R \bar{a} pased each e ne in the space domain. $\frac{0}{5}$ em₁ current equation ា
ឆ្នាំ step displacement state $\pmb{\mathsf{\Omega}}$ which eitp of geometry Ω ۲.
M r **tn** necessarily formulation tiffness Here, we need to set lasterial finite pasn st nonline element $\frac{1}{2}$ proper- $\frac{1}{2}$ ਜ
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ment \circ $\ddot{\mathbf{a}}$ $\boldsymbol{\omega}$ where \mathbf{u} Ω $\boldsymbol{\omega}$ Internal forces shown in gig. rectangular Cartesian coordinate system motion is r
Q $\ddot{\mathbf{a}}$ $H₀$ oordinate system for each element, ystem varies H **rt** grangian" formulation (97,98,99,47) for **fect** fixed strain-displacement up and solved. transformation ن
O the equilibrium $\frac{0}{n}$ diobal account geometric pasn $\frac{d}{d} \cdot 1 \cdot p$ continuously as in this cordinate system and stiffnesses are $rac{1}{2}$ the. nonlinearity matrix Thus, the continuously changing equations for The direction of this study. $(\frac{2}{3} - 3)$ geometric H
D
H relationship. $\frac{1}{2}$ each For \mathbf{x} along with **BANCOUTHE** nonlinearity, each element calculated in the element ene
a ×¢ and then transformed to shown entire $\ddot{\cdot}$ the description \checkmark local coordinate $\frac{1}{2}$ nonlinear deforms repres $\frac{1}{9}$ structure Fig. an
G defined \mathbf{p} ente Iocal npdated displace $4.1.5$ Iccal HOID the
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 $\ddot{\cdot}$ \overline{v} Solution **Nethoda** $\frac{1}{2}$ Nonlinear Equitad and a Equations

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11 e h e solution $\frac{0}{10}$ the total equilib-

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 $\frac{0}{7}$ the tangential equilibrium equations

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ur. three 100,101). placements which categories stiffness $\overline{1}$ These **BUD** methoda material p
Ø matrices EOIIOWS. can be properties \mathbf{z} pue generally $\frac{1}{4}$ aza かけの evailable functions classified $\frac{0}{n}$ $(1, 2, 3)$ HHHO $-8, 8, -$

each putppe Aq **Danno candent Total** 10ad $\frac{1}{2}$ load displacenent increment Incremental Load Method $\frac{1}{2}$ is subdivided into load ΔR increments. displacement -513 displacement increments **INCrement** $4.2.4)$ \tilde{H} VR. 2_H tr
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71 obtained obtained

 $\frac{1}{2}$ Iterative Method $(5, 4)$ $4.2.5)$

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O \mathbf{u} pue from Ioad equilibrim Total $\tilde{\mathbf{e}}$ $\ddot{\mathbf{r}}$ Ō į. n
118 \mathbf{r} Ω discrepancy けいゆ lassified thees external t.
G Ioad **MITHING** unbalanced cbtained by ជូតក្នុ r.
M r.
00 applied into joint $\frac{1}{2}$ Irom reached method the iterations, Ioad three load, thus subtracting internal resisting load the equilibrium in one step \mathfrak{a} iteration **Bnd** methoda a desired degree. tangent r.
H $\ddot{}$ $\frac{1}{9}$ H. represents けいの initial **BALLITIONS SURFER** 126 performed iterative **Iterative BILLINESS** Dending $\frac{1}{10}$ Unbalanced method until **Eethod** magnitude method, $\frac{1}{2}$ method, $\frac{0}{3}$ Can the
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divided **HOT** Tuto $-11e$ time Þ discrete dependent **DUBUNN** analysis, $\frac{0}{n}$ t1me the intervals time domain each r.
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با Analysis

Procedure

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 Nonlinear Time Dependent

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Si cracking degree iterative **APPRIMALIANS HOT** load total \mathbf{a} provided pagn generally fness incremental Detter increment one コロー load is divided $\frac{0}{16}$ to enhance r.
D incremental during methoda accuracy. accuracy. tensile \mathbf{r} path-dendent に切り ተ
0 nethod. iterations. yield the the intermediate either tangent $\frac{1}{9}$ $\frac{0}{n}$ regions, **HOT** load an
11e into accuracy **HO**
10 concrete stuctures, method generally three load mainly due final solution this study, the combined $\frac{8}{0}$ $\frac{0}{12}$ that increments, **iterative BOOKSTORS** the solution. bna $\frac{14}{11}$ to the final solutions la desirable **Bethoda** \mathfrak{a} gives $\frac{0}{4}$ and progressive the
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angularized initially can apetnante requires iteration. \blacktriangleleft triangularized **Iterations** $\ddot{ }$ antage angen $\mathbf{\hat{a}}$ that \boldsymbol{q} the largest thituese that $\frac{1}{2}$ on the the arrive at the the same stiffness **Th**
OH tangent method other hand, the Gaussian number stiffness requires be peat for $\frac{0}{10}$ solution, but seentrial stifferes iterations, elimination, which is けいの nas
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Conbined Method

 $(Fig. 4.2.c)$

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m $\frac{0}{16}$ solution $\frac{0}{m}$ $\frac{0}{n}$ concrete and temperature every non-mechanical strains defined have u
. e
T time time t_{n-1} and **the** time step Then part total non-mechanical strains ε^{nn} , and o
ct $2.2.1$. ateps stepa ີ
ຜ **une** same_s calculate the $\frac{0}{10}$ time n^{2} added to the know all the current is performed considered t_n ; $n = 1, 2, ...$ the structure. duration t_n which would produce the The junctions by the mechod described steps. time $\Delta \epsilon_n^{nm}$ ٣. changes ocurring in the analysis. equivalent thus in which previous time, joint step, on
G N. Xiste N Fane N 13 0
m E
O Evaluate displacements e
S these n
M to creep and have joint load tates EDIIONS incremental already \mathbf{a} time $-572 \frac{1}{2}$ H.
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 $\Delta R_{\rm n}^{\rm nmm}$ $\pmb{\parallel}$ $f_{\rm V}$ E T $_{\rm E}$ $\Delta \epsilon$ nm $\frac{a}{4}$ (4.3)

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procedure Physically, AR^{nm} (4) cań a
C obtained by the putwollog

 $\hat{\mathbf{u}}$ Lock e 11 ens joints against displacements a
m time

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 770 \circ ٣Ť $\mathbf{\sigma}$ maintain Ă $\ddot{\mathbf{o}}$ roduced $\frac{1}{2}$ $\ddot{\circ}$ Ω re d rean $\frac{1}{2}$ $\frac{2}{3}$ Butzne displace. all the by the shrinkage Calculate time restraint stnice_t and steps the temperature changes which would locked $\frac{1}{\sigma}$ of the non-mechanical strains t_{n-1} and a d a required by integrating the $\mathfrak{n}^{\mathfrak{n}}$ $\frac{11}{11}$ e
4 けいの t 1me joints de1s **Stresses** $\mathfrak{n}^{\mathsf{t}}$ arexe $\frac{1}{\sigma}$ an a have

does $\begin{array}{c}\n\mathbf{1} & \mathbf{3} & \mathbf{0} \\
\mathbf{5} & \mathbf{1} & \mathbf{0}\n\end{array}$ 确作代价价值。 IIJ **OHOL** ene
a computing should be opposite n
M 10H $\frac{1}{2}$ n
In \mathbf{a} cause correction **AL** explained $\Delta R_{\mathbf{n}}^{\mathbf{n},\mathbf{m}}$ eine $\frac{0}{1}$ excluded from Atm since actual physical straining, and can $\frac{1}{2}$ by Eq. (4.3) the **atep** joint in section HOT HOT \mathfrak{p}^{\dagger} locking loads release $\frac{1}{10}$ $2.2.3.$ IIs aging strain increment calculation of the the
e ene
e calculated above. joints aging strain and
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دفعا peer adding external joint load increment pinto nd
Ta $\frac{1}{11}$ load increment tine
1 **Left** ateh OVEZ $\begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}$ from $\Delta R_n^{n,m}$ load increment time one
O depe to non-mechanical $\begin{array}{c}\n\uparrow \\
\uparrow \\
\downarrow \\
\uparrow\n\end{array}$ $\Delta R_{\Omega}^{\dagger}$ AR. and unbalanced \vec{c} r
M ehe obtained **SUTEITS** equivalent σ \prec

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ART $\ddot{}$ $\Delta \frac{R}{2n}$ $\ddot{\bullet}$ $\frac{1}{2}$ = $\frac{1}{2}$ (4.4)

may and Then **DOL** 74 h R
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R α unbalanced $\frac{1}{9}$ of equal magnitude, divided Joad into load iteration increments HOH $\frac{1}{2}$ incremental Dericined **AR,** each **SOX** Ioad $\frac{0}{1}$ e a ch analysis which peor

isplacement angent uzzent $\frac{1}{2}$ geometry atifieso **MOXE** transformation tangent a n d $\frac{1}{12}$ $\frac{\mu}{2}$ material **BALLETORS** 10401 matrix **DRODORYTHOM.** coordinates TOT HOT $\frac{1}{2}$ $\frac{1}{2}$ each elenent butsn Assemble elene ø current 'n based naonzas \bullet b Ħ $\ddot{\bullet}$

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and displacement transform (5) solve increments into $\frac{1}{n}$ $\begin{matrix} 2 \\ 1 \\ 2 \end{matrix}$ Iocal \mathbf{H} $\begin{array}{c} \mathbb{Q} \\ \mathbb{Q} \end{array}$ coordinates 707 displacement \mathfrak{a}^{\dagger} obtain **Increments** element $\frac{D}{n}$ puə

 $\overline{4}$

 \mathbf{a} strain-displacement relationship, displacement obtain \tilde{c} current Compute strain increment increments by using nonlinear total strain ო
• and add **de Fromene Prement** \mathfrak{a} incremental previous total e
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elenent tatal **OCHNeilt** \hat{a} displacements total length and displacement transformation matrix. Add joint displacements r. displacements r, update member \overline{H} n
O previous geometry, Based on current total $\ddot{ }$: e : $\frac{1}{2}$ ae
A update

 $\mathbf{r}^{\mathbf{r}}$ 6
22 mechanical strain ε^m . Compute current on
G changes $\vec{\Omega}$ taking load reversals なわれのなかーなわれなけい \hat{S} creep, shrinkage mor₁ Subtract current total non-mechanical strain ϵ^{nm} current total strain (c-c^m) law valid for and 1110 puțbe account. $\frac{0}{10}$ **n**
10 concrete のけらの頃の obtain the present current and $\mathbf Q$ HAOB DODLINE temperature time teter atep

ct t. loads total н ransform ansformation matrices $\begin{array}{c} \mathbf{1} \\ \mathbf{2} \\ \mathbf{1} \end{array}$ $\begin{pmatrix} 6 \\ 9 \end{pmatrix}$ STRESSE into Compute element global coordinates using updated for each element \mathbf{r} end forces by integrating asemble for in local coordinates, and e u e internal displacement current resisting

tatal external joint Ioads $\sum_{i=1}^{n}$ $\frac{\sigma}{\sigma}$ obtain unbalanced $\frac{1}{2}$ loads R^u. (4.5)

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Subtract

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tn $\frac{1}{\sigma}$ $\frac{d}{dx}$ \bullet $\mathbb{Z}^{\mathbf{N}_t}$ and ۹
٥ back $\frac{1}{\sigma}$ step \ddot{a} Steps $\frac{1}{2}$

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again. time Ioad allowable σ loads $\frac{1}{2}$ de 15 Step \mathbb{R}^V Þ بر
۳ \mathbf{H} かけの $1 + u$ ø and tolerances. the
S continued added ene end iterative $\frac{0}{H}$ \mathfrak{a} nntil けいの the r
F th is peot final unbalanced procedure increment point Joad ene
S de₁₆ $\frac{1}{2}$ loads $\frac{6}{5}$ current ての $\frac{1}{\sigma}$ $rac{1}{2}$ $\frac{1}{2}x$ proceed $\frac{1}{2}$ 916 the 는.
하 pentated EHALL next performed $\begin{matrix} 1 \\ 0 \end{matrix}$ next

4.4 Convergence Crit stia:

displacement **This** second assured by the magnitude Ω iterative u
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ত olving $\frac{1}{2}$ methods, heaured which equilibrium is violated. increments $\frac{5}{2}$ magnitude けいの ր.
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Up nonlinear by the magnitudes convergence criteria. Boouzacy $\frac{0}{12}$ the equitriprium $\frac{0}{12}$ undalanced いけの o
N けいの **HILB4** ene
e $\frac{0}{n}$ total displacement additional equations end
G loads. criterion This can $\frac{0}{10}$ a n ココの Y iteration .
თ $\frac{1}{\alpha}$ e y e

ment displacement primary convergence tolerances criterion **GXCBSDXC** increment **HOT** ehis |-4
00 violation e
Te z atio **also** study provided for tolerance provided. tolerance of equilibrium, criterion. the displacement sru? and $\frac{13}{8}$ せいけん kinds of displacement the second study. \mathbf{r} the unbalanced load criterion praze **Phe** tr.
W against **HARTH** r
M けいの **C**
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O $\frac{1}{10}$ displacert
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uitw **Search** (here, ratio munimum U tolerance isplacement วิธ m
OH **Mord** けその absolute components displacement is defined zatio value \mathfrak{a} $\frac{0}{12}$ 0
0 or
O $\frac{0}{16}$ the displacement i
G follows. compared $\frac{1}{2}$ C SAD displacement meaning **Niteh** Fo
To e a ch $\begin{array}{c}\n\uparrow \\
\uparrow \\
0\n\end{array}$ tanalational vector **MDCREECHE** displacement Ioad $\overline{1}$ step, one

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ខ $\frac{1}{2}$ ua
G a ne $x^{\frac{1}{n}}$ $\frac{1}{2}$ Calculate $\frac{0}{m}$ atter and o u d $\begin{array}{c}\n\bullet \\
\bullet \\
\bullet\n\end{array}$ placement component component rotation increment, r ch $\Delta z_{\mathbf{k}}^{\mathbf{1}+\mathbf{1}}$ jth component for (i+1)th iteration (see total displacement iteration and $\Delta r_1^{\frac{1}{2}+1}$ following o
10 enly), the has នីនា befined ana
a the maximum zatios maximum rotation after other similarly increment $\frac{1}{2}$ e
C displacement the with maximum absolute displacement the displacement **TITET** $\frac{1}{2}$ $\frac{0}{n}$ the increment. rotation iteration. **Lida** increment and component Fig. 4.3.1). increments. rotation. increment 76
7 value asoddns e n d u.
H $\frac{0}{m}$

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$$
b_{d} = \left| \frac{\Delta z}{z_{\frac{1}{2}}^{+}} \right| \qquad r \qquad \rho_{z} = \left| \frac{\Delta z_{k}^{+1}}{z_{k}^{+}} \right| \qquad (4.6)
$$

Lhen $\frac{1}{2}$ displacement ratio D $\frac{1}{9}$ benineb ζ

 $\mathbf D$ \blacksquare aya larger $\frac{0}{n}$ \mathbf{a}^{σ} pue σ (4.9)

gence **Hhe** tolerances displacement ratio as follows. $\ddot{\mathbf{c}}$ is compared with three conver-

 \overline{z} $\frac{1}{2}$ ِ
پ $\mathbf{r}^{\mathbf{t}}$ \mathfrak{n} $\frac{1}{1}$ H
M H H
M 目标 Ω Ð $\mathbf{\overline{o}}$ O D 707 Ю 701 707 \vee İΛ \vee $\overline{1\Lambda}$ λ $\frac{1}{4}$ $\frac{1}{2}$ \mathbf{r} \mathbf{r} \mathbf{r} changing stiffness) intermediate m. final load Ċ, H)
V **C**
esp peeceed continue iteration proceed to next continue iteration previously to next step) Toad Formed steps) load step time atep. and triangularized

のけい けいこうのめ HOT next iteration.

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Displacement

Ratio Tolerance

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 $5x8$ $\ddot{\mathbf{a}}$ sively even though the There ب
با $\boldsymbol{\mathfrak{a}}$ possibility that displacement equilibrium convergence may be violated crise-

 Δz_{\pm} ۰, \mathbf{H} $x \Delta r_i$ x (the smaller of $\left| \frac{c_d}{\Delta r_j} \right|$ and $\left| \frac{r}{\Delta r_k} \right|$) ; $1, 2, \cdots, n$

 $\tilde{\omega}$ If $\left|\Delta x_{j}\right| > t_{d}$ and $\left|\Delta x_{k}\right| > t_{k}$, set

 $\Delta r_{\frac{1}{2}} = \Delta r_{\frac{1}{2}} \times \left| \frac{t}{\Delta r_{\rm K}} \right|$ $\rightarrow \pm = 1, 2, \cdot \cdot \cdot, n$

number of degrees of freedom in the If $|\Delta \mathbf{r}_j| \leq \mathbf{t}_d$ and $|\Delta \mathbf{r}_k| > \mathbf{t}_k$, set

 \tilde{c}

 $\Delta r_{\text{i}} = \Delta r_{\text{i}} \times \left[\frac{t_d}{\Delta r_{\text{j}}}\right] + i = 1, 2, \dots, n, \text{ where}$
 $\Delta r_{\text{i}} = \frac{t_d}{\Delta r_{\text{j}}}$ Structure Ø r.
Vi $\frac{1}{2}$

increment \mathbf{a} α rement $\frac{1}{2}$ Ark for the current iteration

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c allows us to use either the initial stiffness method

tangent stiffness method for iterations

To guard against unfavorable situations of the dis-

the

desired degree of accuracy.

And an appropriate choice

results to

tolerances, we can obtain intermediate and final

By providing appropriate values of displacement ratio

t_o, form new stiffness for hext iteration.

 \mathbf{H}

 H_h

D

If $\left|\Delta z_{j}\right| > t_{d}$ and $\left|\Delta z_{k}\right| \leq t_{p}$, set

nonlinearities (Fig. 4.3.c), maximum allowed values of the analysis (Fig. 4.3.b) or load reversal analysis with material placement overshoot which may occur in geometric nonlinear isplacement increment (t_d) and the rotation increment (t_r) the displacement vector r has the maximum displacement each iteration are provided. Suppose the jth component Arj, and kth component has the maximum rotation

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M each \blacktriangleright $\frac{1}{2}$ or $\boldsymbol{\mathsf{w}}$ **Lhe** provided p. iteration. 'n maximum unbalanced ហ
ប្ r† μ. m
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H m Fied. $\frac{1}{10}$ \mathfrak{r} munixem $\overline{0}$ $\frac{1}{10}$ the zená noment maximum unbalanced Ω etadau surebe allowed $\overline{\mathbf{u}}$ $\frac{0}{10}$ \vec{r} such $\bar{\mathbf{p}}$ load 707 Ŵ C
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S allowed each iteration Borce $\ddot{\circ}$ ÷. \mathbf{p} $\ddot{}$ H_0 and
B ceil \mathbf{o} a
u d $\mathfrak{p}_{\mathbb{H}}$

step ehe
e $\mathbf{\bar{u}}$ **Freneration** pepronded avove $\frac{1}{2}$ $\frac{1}{2}$ naximum number peurc $\frac{1}{2}$ $\pmb{\omega}$ addition are
B ceiling $\frac{1}{2}$ allowed $\begin{array}{c} 7 \\ 0 \\ 0 \end{array}$ each stringent. \vec{c} $\frac{1}{2}$ $\frac{0}{16}$ peat m
O
H $\begin{array}{c}\n\uparrow \\
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M 11mit **allowed** the
Le peot tolerances convergence $\frac{1}{2}$ naximum number steps, Hor number t he described and $\frac{0}{10}$ reura toler $\frac{3}{44}$ iterations $\ddot{\mathbf{o}}$ o
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61 m $\ddot{\mathbf{0}}$

$\ddot{\bullet}$ **u Nume** \mathbf{H} $\frac{1}{\Omega}$ $\frac{\alpha}{L}$ Examples

$4.5.1$ Time Dependent Analysis $\frac{0}{n}$ ĝ. Conc: $\frac{11}{9}$ $\frac{1}{6}$ $5777d$

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S nicin shrinkage Concre procedure usous \mathbf{r}_n $\ddot{\mathbf{z}}$ \mathbf{H} Idered tension erent $\mathbf{\bar{r}}$ Ω In order load u
U $\tilde{\mathbf{r}}$ reep $\ddot{\mathbf{r}}$ $E19.$ t.
M strain history loading $\pmb{\omega}$ history بىيا
04 ÷, n q $\begin{array}{c}\n\bullet \\
\bullet \\
\bullet\n\end{array}$ **bemusse** concrete **assumed** $4.4.$ \mathbf{c} **une** denonstate $\ddot{\circ}$ **ages** and temperature history is analyzed modulus linearly \mathfrak{p} prism having \mathfrak{a} **DHS** $\pmb{\ast}$ $50,$ given. $\frac{1}{2}$ specific elastic art
P \mathfrak{c} assumed to vary with simple erime[®] only \blacksquare Inoi $\frac{20}{3}$ both in compression compliance dependent one and
S time numerical 加竹像 eares \mathfrak{r}_4 steps ELTTT \blacksquare give analysis თ
O curves $\frac{0}{12}$ ø ö time Ħ $\pmb{\sigma}$ **DECB TASS** 707

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ਘੁਲਾ $a_1(\tau)$ [1-e-10⁻ⁱ $(1 - 1)$

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Fig. $\begin{array}{c} 4 \\ 5 \\ 3 \end{array}$ Displacement **History** $\frac{1}{2}$ |
|p Concrete Priss

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Þ $\hat{\mathbf{r}}$ \mathbf{c} \mathbf{r} 며
무 t_4 . o
. prom puisn evaluated $\frac{1}{\sigma}$ 4.44255 have loading Ĥ. \sim m Calculate displacement Calculate mechani Calculate each Calculate ru₁ ⊸റ **The** $\tilde{\ }$ aya simple give ង
ក្នុ بيب \mathbf{u} \mathbf{x} a å e time \bullet following values 10^{+2} example ζ \bullet Analysis (3.52) ene
a ca1 numerical creep \mathbf{r} $5u$ the incremental the n
D
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Fig. 4.7. A Truss Subjected to Compression

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u(x,y) = u_0(x) - y \frac{dv(x)}{dx} = \phi u - y \psi_x \left\{ \frac{v}{\theta} \right\}
$$
 (5.7)

u(x,y) and v(x) may be expressed \mathbf{a} terms $\frac{0}{10}$ $\sum_{i=1}^{n}$

 π (x,y) = $\zeta \frac{1}{\phi}$ (x,y) = $\frac{4}{1}$ $7 - 5 - 5$ (5.5) (8.5)

Axial strain $\epsilon(x, y)$ is defined by (201)

 $E(x, y) = \frac{du(x, y)}{1 + h(x)}$ $\begin{matrix} 0 \\ x \end{matrix}$ + $\frac{1}{2} \left(\frac{dv(x)}{dx} \right)^2$ (01.9)

ă ment which the Ommont. second term represents the nonlinear displace-

r
O equations which $\tilde{\zeta}$ ordinates ¢ deformed state. states formation increments Au and Av. rent tate. note that the origin and the direction of the local cochanging. state A H $\frac{0}{n}$ Fig. 5.2.b a frame And state B representesents the next state from the curx,y, and the length of deformation. with Total, incremental are
B State the
 valid at displacement increments A represents the current **State** elenent is shown in its various **bhe** \circ represents As the frame and ene current element are tangential state ene
S $\frac{D}{H}$ element deforms, $\overline{ }$ Laiqinal deformed equititin and the will be decontinuous- $\frac{5}{1}$ $\frac{a}{1}$

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Erom $\frac{1}{\circ}$ total values with the puerions $\frac{1}{6}$ $\frac{1}{9}$ Consider following current state yu, w $\overline{\mathcal{L}}$ Einite expressions and the incremental A, with corresponding change strain can $\frac{1}{2}$ VE. e p e o
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၈ $\frac{1}{2}$ $\begin{array}{c} \nabla \mathbf{r} \\ \nabla \mathbf{r} \end{array}$ t
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 $\frac{2}{\pi}$ $\Delta \nabla$ n Q $\pmb{\mathfrak{g}}$ $\frac{2}{3}$ $\hat{\phi}$ $\leq \phi$, $\Rightarrow y \neq y$, \geq $\frac{1}{2}$ $x^2 + 6$ $\begin{matrix} 7 \\ 4 \end{matrix}$ $\frac{d}{dt}$ (5.13) (5.12) (11.9)

 $\frac{d\Delta v}{dt}$ $\ddot{\mathbf{r}}$ $\frac{1}{2}$ \tilde{y} x Δx (5.14)

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ρ \mathbf{r} $x_4 + y_6 = 0$
 $x_1 + y_6 = 0$ \overline{H} (5.15)

strain-displacement relationship at けいの -17.2

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 $5 - \frac{1}{2}$, $\frac{6}{2}$ $\frac{6}{2}$ (1-2p), $\frac{6}{2}$ (2+1+2p), $\frac{2}{2}$ (2-3p), $\frac{2}{2}$ (1-3p)

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 $d\frac{1}{2}$ $\frac{1}{2}$ $(\frac{R^{\frac{1}{2}} + \Delta R^{\frac{1}{2}})}{\Delta}$. = Vv^{dE}(b+bb)dv (5.23)

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N $\begin{array}{c} 1 \text{ or } \\ 0 \text{ or } \\ 1 \text{ or } \end{array}$ \ddotmark $\begin{array}{c} \mathbf{p} \\ \mathbf{r} \\ \mathbf{p} \end{array}$ $\begin{array}{c} 10 \\ 7 \end{array}$ $\widehat{\mathbf{u}}$ $22)$

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ជ equations (5.22) into $\frac{1}{10}$ equilibrium change.to e
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O Eq. (5.23) atate t we obtain the $(R^{1} + \Delta R^{1})$. total $\frac{1}{2}$ substitutequilib-

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E^{j} + \Delta E^{j} = f_{V}(\underline{B}^{T} + \underline{c}^{T} \underline{c} \Delta \underline{r}) (\sigma + \Delta \sigma) dV
$$
 (5.24)

an d are neglecting the then **HAe** betained incremental $\frac{1}{2}$ higher Buttoezagna equilibrium prder term equations Eq. $J_{\mathbf{v}}\mathbf{e}^{\mathbf{T}}\Delta\sigma_{\mathbf{c}}\mathbf{d}\mathbf{v}\cdot\Delta\mathbf{r}$. (5.21) from Eq. at the **State** (5.24) Þ

$$
\Delta \vec{E}^{\dagger} = \int_{V} \vec{B}^{T} \Delta \sigma dV + \int_{V} \vec{C}^{T} \sigma \vec{C} dV \cdot \Delta \vec{E}
$$
 (5.25)

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q Ω **from Nete She** Eq. **Fhe** en e tangential stress-strain relationship (5.25) by replacing $\Delta \underline{r}$ by $\overline{d} \underline{r}$, $\Delta \underline{R}^{\frac{1}{2}}$ by $\overline{d} \underline{R}^{\frac{1}{2}}$ tangential equilibrium the reinforcing steel can be equations **KHHTTTDJ** can be obtained Eor and bo by **4409** $\begin{array}{c} 0 \\ 0 \\ 1 \end{array}$

$$
d\sigma = E_{\rm t} d\epsilon^{\rm m} = E_{\rm t} (d\epsilon - d\epsilon^{\rm nm})
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 (5.26)

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៦ ទ defined cal ene **Ande** Ĥ strain respectively, and E_t is the mechanical strain, (5.56) $\ddot{\bullet}$ de^m u.
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ო and de^{nm} $\ddot{}$ the total strain and the non-mechani-解れの By substituting the incrementerinal increments **29.** tangent modulus (5.19) for ი
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d\sigma = E \, \xi \, \bar{B} \, d\, \xi = E \, \xi \, d\, \epsilon^{h m} \tag{5.27}
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1 ò n incremental \vec{r} itution of $\frac{1}{2}$ $\frac{1}{2}$ following tangential operator Eq. (5.27) \triangleright by the into Eq. equilibrium equations differential (5.25) **District** OPETATOL replacing $\frac{\mathbf{a}}{\mathbf{b}}$ ia
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Sp $\pmb{\mathfrak{h}}$ (1) v $\frac{1}{2}$ r $\frac{1}{2}$ gd $\frac{1}{2}$ y $\frac{1}{2}$ gd $\frac{1}{2}$ gd $\frac{1}{2}$ \mathbf{I} $\gamma_{\mathbf{v}}\mathbf{\underline{s}}^{\text{T}}\mathbf{\overline{s}}_{\textbf{t}}\mathbf{\underline{a}}_{\textbf{e}}^{\textbf{n}\mathbf{m}}\mathbf{\underline{a}}\mathbf{v}$ $\widehat{\mathsf{G}}$ $rac{1}{8}$

 λ g defining $\frac{1}{2}$ following terms

 $\frac{1}{\alpha}$ ue o **Sewrites** $\frac{1}{2}h$ ងី (5.28)

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 $(5 - 34)$

Ieiz $\frac{0}{4}$ geometric **22922** cause these strain-displacement relationship nonlinearity CONSISTS equations tor due the $\frac{1}{2}$ properties. **This** $\frac{1}{2}$ stiffnesses $\pmb{\oplus}$ to non-mechanical lement $\frac{0}{16}$ **Fhe** which are valid nonlinearity since $\frac{1}{2}$ integrations the
D and the geometric the
e elastic elastic desired $\begin{array}{c} \mathbf{d} \mathbf{R} \mathbf{n} \mathbf{m} \\ \mathbf{R} \mathbf{n} \mathbf{n} \end{array}$ are dependent **8555151458** are
a $\frac{14}{50}$ **OCHIMINO** morn **MINTER. the** For performed $\frac{1}{\sigma}$ equivalent load the current on the **SITHMSDSS** on the current originates **Ke hedresentes** in Eq. (5.10). ke and the The tangent stiffness $\begin{array}{c}\n0 \\
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T well. tangent $\frac{1}{5}$ \prec μ. **the** ρ.
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स However, along $\frac{1}{\sigma}$ $\frac{1}{10}$ depth the
b perform the integra- $\frac{1}{\sigma}$ $\pmb{\omega}$ $\frac{4}{5}$ **frame** function according ب
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 $\frac{1}{\sigma}$ $\pmb{\parallel}$ $x x'$ \bar{A} $\frac{1}{2}$ $\frac{3}{L}(-1+2p), \frac{3}{L}(1-2p), (-2+3p),$ $(-1 + 3 p)$ (5.37)

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 $\times x' = \frac{1}{\phi}$ \blacksquare $\sum_{n=0}^{\infty}$ $-y_2$ $\frac{1}{2}$ $\frac{1}{2}$

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B_aB_bdx (5.40)

 $q\bar{q}^*_{\bar{X}}$ \mathbf{u} $\mathcal{N}_V{}^2 \mathop{\mathbb{E}}_{$ (5.41)

well compensates the increased computation time **In** librium state. creased number nonlinear equilibrium equations $x + 1x$ Note sbuthe is not that the H.
J the $\mathbf{\hat{p}}$ necessary requirement exact evaluation of the tangent computation time due to this approximation of iterations required to as discussed in for the solution of **arrive** stiffness chapter for the in- $\frac{1}{\pi}$ ct
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Bre evaluated integration $\frac{9}{11}$ e
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by \blacktriangleright IJ \blacksquare $\int_{A} E_{\xi} dA = \sum_{\xi=1}^{n} E_{\xi} \frac{1}{\xi} \sum_{\xi=1}^{n} A_{\xi} \frac{1}{\xi} E_{\xi} \frac{1}{\xi} E_{\xi}$ (5.42)

 \blacksquare \mathbf{r} \blacktriangleright **SG** \blacksquare $\int_{\mathbf{A}} \mathbf{E} \mathbf{t} \mathbf{y}^2 d\mathbf{A}$ $-\int_{A} E_{\mathbf{t}} Y dA$ $n_{\rm c}$
= $\sum_{\rm i=1}^{n_{\rm c}} E_{\rm c1} y_{\rm c1}^2 A_{\rm c1} + \frac{n_{\rm s}}{1 \pi_{\rm i}} F_{\rm s1} y_{\rm s1}^2 A_{\rm s1}$ $\frac{1}{1-\sum_{i=1}^{n} E_{ci} y_{ci} \hat{y}_{ci}}$ $\frac{1}{4}$ = $\frac{1}{4}$ (5.44) (5.43)

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\mathbf{g}_{\mathbf{q}} = f_{\mathbf{v}} \mathbf{g}^T \mathbf{g} \mathbf{g} \mathbf{v} = f_{\mathbf{A}} \mathbf{g} \mathbf{a} \mathbf{a} \cdot \mathbf{f} \mathbf{g}^T \mathbf{g} \mathbf{a} \mathbf{x} = p \mathbf{f} \mathbf{g}^T \mathbf{g} \mathbf{a} \mathbf{x}
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• a q L ahons 2.50 element matrix, ! ጂ
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: Calculation $\frac{0}{n}$ Strains and Stresses

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ወ lement $\frac{1}{6}$ io. $\frac{1}{10}$ solved discussed For displacement increments variables p, $\frac{0}{n}$ H.
M symmetric e a ch ene For outlined procedure strain iteration $\frac{11}{3}$ global displacement pronid chapt. banded bne $\frac{1}{2}$ $\frac{1}{2}$ σ u. \ddot{a} $\frac{1}{2}$ $\frac{4}{5}$ h e used. equation referred けいの tangential equilibrium equations stress following $\frac{D}{iH}$ course **Hype** $\frac{1}{2}$ solver $\frac{1}{\alpha}$ increments. $\frac{\omega}{\tau}$ procedure 10u t
10 $\frac{0}{2}$ description any putilizing a dd e d the current point noiution $\frac{H}{D}$ $y \in t$ ing
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Equivalent Internal resisting Loads Due to Non-mechanical loads $\begin{array}{c} \mathbb{R}^1 \\ \mathbb{R}^1 \\ \mathbb{R} \end{array}$ which can Strains o
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 $\frac{1}{2}$ $\mathcal{N}_{\mathbf{v}^{\underline{\mathbf{p}}}^{\mathrm{T}}} \sigma \mathrm{d} \mathbf{v}$ (5.54)

 $\frac{0}{H}$ non-mechanical Equivalent load strain increments $\Delta \epsilon^{nnm}$ a re $\Delta R^{n,m}$ calculated o
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O \mathfrak{a} the $\frac{a}{2}$ ង
ភ្នំ increments (5.29)

 Δ $_{\rm R}^{\rm min}$ $\mathfrak n$ $f_{\mathbf{v}^{\mathbf{B}}} \mathbf{T}$ Ethermay (55.5)

 \mathbf{r} this tion Gaussian ternal comparison have $\frac{0}{5}$ Hor \mathfrak{a} HOSPAI bnlike joint $\frac{a}{b}$ dnadrature phe. Deteren calculated both tangent iterative loads $\sum_{i=1}^{n}$ form the $\begin{array}{c}\n1 \\
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S Which t i on EOIIOWS volume f(x) which Each $\frac{1}{n}$ dependent component $\frac{0}{n}$ the alement. is dependent $\frac{1}{2}$ $\frac{0}{10}$ udod the vector $\overline{\mathbf{x}}$ The pue $x₀$ integration $\tilde{\mathbf{y}}$ $\sum_{i=1}^{n}$ only and $\frac{1}{6}$ $\frac{0}{1}$ **U**
0 Δ _Rnm integrated p. $\frac{0}{3}$ function contains $\frac{1}{2}$ performed **DVez** $(A' \times B)$ ø Eunc-

 $0 - t$ $f(x)$ $\int_{A} g(x, y) dA dx$ \blacksquare $M_{\rm H}$ $\sum_{k=1}^{3} w_k f(p_k) h(p_k)$ \int f (p) $f_{\mathbf{A}}$ g (p,y) dAdp $\widehat{\mathbf{u}}$ **u** $\overline{9}$

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 \mathfrak{r}_2 weights 0.112701665379258, x^* 918 Gaussian $\ddot{\cdot}$ \blacksquare integration $6/8$ \mathfrak{p} \overline{z} \blacksquare 0.887298334620742 \blacksquare \mathfrak{a} points $-6/9$ x^{α} $\tilde{}$ and
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 $\int_{\mathbf{A}} g(\mathbf{p}_\mathbf{k}, \mathbf{y}) d\mathbf{a}$

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 \mathbf{o} where n_c \overline{m} steel is the number of layers. concrete layers, \mathbf{u} t. ب
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 $\int_A y \, \sigma \, \mathrm{d} \, \mathsf{A} \quad = \sum_{i=1}^n y_{c,i} \sigma_{c,i} \, \delta_{c,i} \quad \mathsf{A} \quad = \sum_{i=1}^n y_{s,i} \sigma_{s,i} \, \delta_{s,i}$

 \mathbf{R} . λ q the layer integration For example, for each Gaussian integration point

Phe function h(pk) defined ζ $E_{\mathbf{q}}$. (5.57)

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918 $\stackrel{\scriptstyle \overline{t}}{\rightarrow}$ $\frac{\omega}{\Gamma}$ **Hores** f(p) and g(p,y) for the calculation of the components $\frac{1}{2}$ are only three strains shown load vector joint -573 oz the computed by the equilibrium requirements. S₁, S₂ and S₃ are $\frac{1}{2}$, $\frac{1}{2}$, $\frac{1}{2}$ j and S₃ is the axial force. equivalent load vector ΔR^{m} heed form in Fig. 5.3.a. independent internal force S₁ is the moment at joint to be a self equilibrating system calculated, and the tabulated Since these components of the below. o
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۵ Pue ព្
ភូ o ud formed steel tn, concrete Initial けれの **CO** and which $\frac{1}{n}$ prestressing cured. the following events occur. ehe H.
W prestressing anchored Before Force $\begin{matrix} 1 \\ 0 \end{matrix}$ the the abutments steel $\frac{1}{9}$ prestress applied $\frac{1}{2}$ Ħ $\frac{\Phi}{\Gamma}$ \mathbf{P} \mathfrak{a} in. axed ehe tzans- $\frac{1}{2}$

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S the concrete and the prestresing hardens. steel **aza** pended

dether concrete ᄓ after shrinkage analyze 다
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0 $\hat{\epsilon}$ and
P stress.in $\frac{0}{10}$ Shrinkage ្អាប់ the
b concrete STIGE FORE prestressing $\frac{0}{1}$ ene
9 take concrete prestressing place そにのいる steel takes place a
11 events assume $\frac{1}{\alpha}$ the time steel is completely Attauenty. $\frac{0}{m}$ relaxed the transfer that all pended and t
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b 1e $\boldsymbol{\omega}$ t
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ត taken 5762 sioned remaining $\overline{\mathbf{o}}$ is $\overline{\mathbf{s}}$ **the** equivalent shown is given. H
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N place concrete tatel atayiain just in Fig. 6.2.a in which a concentrically pre-tenuoz₃ e a z **Defore** Ioad prism 797 ene procedure shrinkage \mathfrak{p} ิซ
ผ initial the
S **Mith** a
O acting transfer $\frac{1}{2}$ lineariy $\frac{0}{H}$ $\frac{1}{\alpha}$ prestressing **Force** $\frac{0}{2}$ illustrated concrete up the
ue after the relaxation ti
D elastic composite ene EOICE prestresing ξ $\frac{\sigma}{\sigma}$ material $\frac{1}{2}$ transfer prism \ddot{P} simple o
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G $\frac{1}{2}$ proper- $\ddot{}$ -252 h a s then ree1 ິຕ
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• $\ddot{\cdot}$ Shrinkage Analysis of a C.
Concrete Prism Before the Concentrically Tensier $\Bigg|_n$ Prestress Pre-tensioned

 $\frac{1}{2}$ Iterative Method of Solution

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۹ **Pue** Le t steel corresponding $\Delta \epsilon$ s concrete embedded o
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D \mathfrak{g}^{\dagger} Eorce the
b e h e strain $\frac{1}{2}$ shrinkage ក្នុង $\frac{0}{1}$ prestressing the
B ິດ
ທິດ compos-Then

$$
\Delta P^S = -E_A A_B \Delta E^S
$$
 (6.2)

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റ Fhe $\frac{2}{9}$. $\frac{1}{9}$ reasad steel Eorce **SHOUNS** between by the $\frac{1}{3}$ the
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Si shown in the **Difish** and the steel embedded m
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Acs the composite can be Then, **bhe** calculated prism. change $\frac{q}{4}$ H. the
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b composite יט
מ and ΔP 3 prism, $\frac{0}{\omega}$

$$
\Delta \varepsilon^S = \frac{\varepsilon^S + \Delta \varepsilon^S}{\varepsilon^A c} + \varepsilon^{\frac{R}{S}} \frac{\varepsilon^A c^C \varepsilon^S}{\varepsilon^A c} - \varepsilon^{\frac{R}{S}} \frac{\varepsilon^A \varepsilon^A}{\varepsilon^A \varepsilon^A}
$$
 (6.3)

Solving E q. (6.9) $\frac{1}{2}$ **DEB**

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\varepsilon^{\mathbf{g}} = \frac{\varepsilon^{\mathbf{g}}}{1 + 2\pi} \tag{6.4}
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ព H_OH iterative shrinkage generally complex relationship. procedure impossible structures besed as ណ
មា $\frac{0}{3}$ $\frac{1}{n}$ \mathfrak{a} **N1114 the** ahown t h \pm s to
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Tt nonlinear solution $\frac{1}{2}$ Ω dous dn \mathbf{p} α $\frac{1}{2}$

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S prestreatng \blacksquare **INCREMENT** $-E$ A_s A_s A ₅ \mathbf{r} $-453,$ ្គ
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O subsequent Ω \overline{v} 6.977^k ene r 19. e
U error involved by resent m_rns or shrinkage a
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ທ initial \vec{c} 6.2.a ΔR concluded that Le rm cn1y 0.12% of which successive the exact cozzections Ħ r. the exact can be prestress PO 6.767k. represents ы
Ч naing the solution, and corrections. (9.9) calculated by Eq. value **bhe** the **This** gives ene
9 represents initial prestress \sharp HEILSH represents 180k. $\frac{0}{n}$ First **1oss** ជ
ព a d u ម្ពុង order **the** With numerical data $\frac{0}{n}$ acceptable **Hhe** zapid **2088** o u a .88. rest (6.2) and e ri e approximation gives 竹片竹叶竹 $\frac{0}{10}$ HHHHH approxima- $\frac{0}{m}$ $\frac{1}{2}$ o prestress HOROS. NOte the the valzapzo Ø aoluzapic $\frac{0}{m}$ (6.4)

te. \mathbf{S} performed tressing the Then composite ene
S $\frac{1}{2}$ steel a single step by applying analysis i
S emera included. n
A in which たけの transfer the
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b $\frac{0}{n}$ **DIGREE SER** Eutwollog $\frac{0}{n}$ o
U C c an **Pre**loads ប
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- \overline{c} $\begin{array}{c} \bullet \\ \bullet \end{array}$ joint Joint 5u₅ Joint discussed in section 6.6 tion ष्ट्र
रा has. loads due to seat_s loads the time taken place. anp ane $\frac{1}{10}$ \mathfrak{a} $\frac{1}{6}$ o
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O the P_{H} $\frac{1}{2}$ $\frac{1}{9}$ shrinkage prestreaing **Lhe** transfer discussed and the calculation calculation after of concrete ۳. Borce the
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- \hat{u} bead **rt Tan** $\pmb{0}$ Ioad Ħ, $\frac{1}{2}$ since $\frac{0}{11}$ **the** most frame. $\frac{0}{n}$ the. **Dead** frames load are es.
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$\frac{1}{2}$ Analysis after ehe Tran 'n $\frac{1}{2}$ $\frac{0}{n}$ Pre stress

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b $\frac{0}{n}$ prestreathe concre temperature Η stiffness $2 - 7$ m
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O transfer various ζ prestreatng stee1 frames. o
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O history, $\frac{1}{2}$ time \mathfrak{a} $\frac{0}{H}$ Procedure \vec{c} $\frac{1}{2}$ Prestress けいの Calculation dependent and prestressing aces₁ element ehe developed the
b end
S creep, loads $\frac{1}{2}$ loads composite $\frac{1}{9}$ **o**
P steel due to shrinkage previously CONSTANTION **Di**
Dip **SURBITS** H. dasusaed frame, live included and a
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$\ddot{}$ Analysis lo. |m Post-tensioned rrames

σ $\ddot{\bullet}$ \rightarrow Analysis $\frac{1}{2}$ the Transfer $\overline{\mathsf{P}}$ Prestress

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Q \mathfrak{o} HOT **ARMS** resulting formula the e
B with post-tensioned takes the
e steel from concrete gradually during the tensioning $1.1e$ prestressing place (101) u.
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O gradual **BALLUCEURS force** \mathfrak{g}^{\dagger} force e
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ਹ end. decrease prestressing friction H.
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Co e p d e applied **Hibe** ahown prestress $\frac{1}{5}$ decre c a n r
J $\frac{1}{2}$ HOTE Fig. ិ
ត steel ัด
ต prestreaing $\pmb{\sigma}$ H.
M and
a calculated $\frac{1}{2}$ **6.2.8** けいかけのけの and the Opera- $\begin{array}{c}\n\uparrow \\
\uparrow \\
0\n\end{array}$ tension-**Pre-**H₁

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Prestresing

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nd ioning forces pua with ζ

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 370 \mathbf{r}_B m steel subtr $\ddot{\bullet}$ $\ddot{\mathbf{r}}$ H $\ddot{\mathbf{N}}$ \mathbf{r} $\frac{a}{a}$ an
Can \bullet -614 \pmb{r} adae Su_I: can tendon o
O $\ddot{\Omega}$ **D** $\frac{6}{5}$ Eozces ζ Summarized and
S berved. ehe Ω shows the Detaen corresponding concrete aase D)
U) Then the EOIIONS. body **Phe** prestresing **frame** decrease diagrams analysis 야
규 transfer $\frac{0}{11}$ Ľ procedure \mathbf{u} itee **the** the $\overline{}$ and **Pres** Eorce $\frac{1}{3}$ $\frac{1}{9}$ p which intessing \vec{r} **EADL/L** rt. con-H S.T.S $\ddot{}$

pue prestresing strain tensioning けいの Nhen ζ force aya there end, stee1 u
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11e pres \mathbf{r} **2688** iing steel nemen \mathbf{r}

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 \mathbf{r} $\pmb{\mathfrak{u}}$ Curvature Eriction coeurticient

 $\mathbf{\pi}$ $\pmb{\mathfrak{g}}$ Wobp1 $\ddot{\circ}$ friction coefficient

 $\sum_{i=1}^{\infty}$ point **N1th** ה
כ \mathbb{E} q. slong $\widehat{\mathfrak{g}}$ $\frac{1}{2}$ \cup $\pmb{\mathcal{Z}}_i$ tendon by \bullet can calculate **Butazes the** from **Pres** ene $\frac{1}{11}$ **Saing** tens ioning Eorce e
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Du each initial tensioning steel have Dreatream \bullet segment constant $\frac{1}{10}$ force, **Stee1** taken force segment $\frac{P}{Q}$ e
S $\frac{1}{9}$ けいの Eorce H.
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- $\frac{1}{2}$ everaging Calculate each けその segment prestressing end Force steel œ segmen ct **HOTO®** $\frac{1}{2}$
- \overline{c} \circ Subtract the loss m the
C prestresaing n
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O steel segment to anchorage EORCES $311D$ from each
- $\left(4\right)$ procedure Calculate n
D
O described joint in section 6.5. loads due to pres \vec{r} n
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B
B Ø ζ $\pmb{\mu}$
- \tilde{g} and not **Which** Analyze **bhe** included, **MO MARAMONA** dead load. the plain or $\frac{1}{2}$ the $\frac{0}{1}$ reinforced concrete joint loads the prestressing due $\begin{matrix} 1 \\ 0 \end{matrix}$ steel Prestre frame, i
G r.
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$6.4.$ $\overline{\mathbf{v}}$ Analysis after **Phe** Transf $\frac{1}{2}$ $\frac{1}{2}$ pres \overline{r} **Tess** $\frac{1}{2}$ Bonded

 $\frac{1}{2}$

Unbonded Frames

 $\frac{1}{2}$ Hor che unbonded. After quet the
9 $\frac{1}{2}$ **Exames** grouted transfer $\begin{array}{c}\n\bullet \\
\bullet \\
\bullet\n\end{array}$ $\frac{0}{n}$ bonded frames DIESTESS **Phe** and prestreatng Tert ongrouted steel

 \bullet run $\mathbf \Omega$ ب
ها ement tween $\pmb{\times}$ r. cept $\frac{1}{2}$ $\frac{1}{2}$ analyzed For Ħ $\frac{1}{n}$ $\frac{1}{2}$ a u a $\frac{0}{7}$ n
T concrete continuous, so that the composite structure, bended unbonded structures stiffness concrete and the anchorage $rac{1}{2}$ and enamene various points, $\frac{0}{11}$ 947 aug
3 $\frac{1}{2}$ time prestressing prestressing steel prestressing displacement pue the displacements dependent there reet is an interaction be-1oads steal field are
a **BICER** anp $\frac{1}{2}$ $\frac{1}{9}$ and independent tnebuded \mathbf{p} to fricsutezas frame transfer. H. $\frac{1}{i}$

unbond tion. $\frac{1}{\alpha}$ $\frac{1}{\alpha}$ \mathbf{u} tructures illustrate p, ene
B simple basic beam procedure with an unbonded $rac{1}{2}$ the
o analysis straight $\frac{0}{10}$

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bna The eccentric $\overline{\mathbf{u}}$ material $\ddot{\mathbf{o}}$ H, $\frac{1}{2}$ prestresing to₁ properties $\frac{1}{2}$ taken Ieets 916 into bemuned awous account ŗ \vec{c} m
D
H $E1.9$ 9
Q \bullet simplicity linearly σ \bullet $\ddot{ }$ p. \mathbf{P} \mathbf{u} $\pmb{\mathfrak{g}}$ \blacksquare analyzed ast. Ω

 $\frac{1}{2}$ beained strain ane lected. **friction** Ω $\boldsymbol{\mathfrak{m}}$ **Fease** re of concrete \vec{c} 787 tn, incre μ. the
B train \mathbf{u} ζ q **Phila** ्
ज Detwen uniform live eppiying ないの **D** beam $\frac{1}{2}$ strain the $rac{1}{2}$ $\Delta P / E$ load w. a u a nwohes a throughout incre the concrete $\sum_{n=1}^{\infty}$ the prestreathd increase putunsse te
So Following in e H. t. e h e corresponding Fig. 6.4.a $10₁$ e n e e
T tendon $\frac{1}{2}$ a $\frac{1}{2}$ tra
O steel end moments prestressing ateel e n e steel the
De steel and and
B Stee1 increase $\frac{1}{2}$ $\frac{1}{2}$ the level which and tenbe quet eife strain forces $\tilde{\mathbf{o}}$ H \mathfrak{a} t.
B rt force $\frac{0}{1}$ $\frac{1}{1}$ ene the neg-다
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 $\frac{1}{2}$ $\frac{1}{2}$ Eccentric **Amum** Average bending pending compression Ap at the moment at moment $\frac{0}{1}$ **biig** $\begin{array}{c} \mathbf{v} \\ \mathbf{w} \\ \mathbf{w} \\ \mathbf{v} \end{array}$ midspan andere steel level. ane \int_{0}^{∞} \mathfrak{a} .ب
M $\pmb{\epsilon}$ **the** $-$ x e $x -$

Equating the \bar{r} n
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O **Btee1** stain level **LUCTEBE** H_OH the te teel and
B the CONCIST **ID**

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a parameter $\overline{\mathbf{a}}$ and the radius $\frac{0}{4}$ $\mathbf H$

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Eined $\frac{1}{5}$ $19.19.$ σ $\sum_{i=1}^{n}$

However r.
O cannot syswie **001** $\frac{5}{5}$ **the** equati $rac{1}{2}$ H_0 $\frac{0}{4}$ PP $rac{1}{2}$

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የ $\ddot{\bullet}$ Analysis of Unbonded Frames

 $\hat{\mathbf{a}}$ Analysis of an Unbonded Frame Including Friction

 \overline{a} **Analysis** \overline{a} e
B Unbonded Frame Neglecting Friction

 \mathbf{e} An Unbonded Simple Beam Example with diven **Data**

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 $= 8\sqrt{2}$ \blacksquare \blacksquare \bullet k/kt **atter**
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200 $\frac{m}{r}$ teranster \$ 344 $\frac{1}{2}$ $-5 = 3 - 7$ ÷. b) B $\frac{2}{3}$ **EAA** w ō .
Ul $\frac{\infty}{\infty}$ \bullet \mathbf{r}_c × -
23
24 $\frac{1}{2}$ $\ddot{\bullet}$ $\vec{0}$ s. 0.052 $\frac{1}{\epsilon}$ $\frac{1}{2}$ $\frac{2}{\alpha}$ $\frac{1}{2}$ $\lim_{n\rightarrow\infty}$

 $\int_{-\infty}^{\infty}$

kh1 lution, $H₀$ $\frac{1}{2}$ **Ht** complex $\frac{1}{2}$ \overline{o} Ilowing $\frac{1}{2}$ shrinkage in which the solution is represents naan structures iterative beaused analysis of prensioned $\mathbf{\hat{\mu}}$ succesive **With** 70 proeedure, general structures. noniinear material propertie correction given by a similar to the Erames \vec{c} **SCITES** $\frac{1}{9}$ procedure before previous each term ow **in** tzans $rac{1}{2}$ けいゅ 50
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 $\hat{=}$ increase Arddy $\pmb{\epsilon}$ $\frac{0}{5}$ the concrete beam. Phe $\frac{\omega}{\zeta}$ ω \mathbf{H} $\mathbf{\hat{p}}$ iΩ $\ddot{\mathbf{0}}$ **SH25** Ē. \Box

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 \triangleright $\frac{1}{2}$ $\pmb{\ast}$ $\begin{array}{c} 2 \\ 2 \\ 0 \\ 0 \\ \vdots \end{array}$ E
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C
C $\ddot{\mathbf{0}}$ $\frac{1}{x}$
 $\frac{1}{0}$ $\begin{array}{c}\n\mathbb{Z}^2 E & \mathbb{A} \mathbb{S} \\
\mathbb{Z}^2 E & \mathbb{S} \mathbb{S} \end{array}$ $\frac{11}{9}$

Phae corresponding increase in the rest_e **forc** $\ddot{\bullet}$ r.
S

 167 $\pmb{\mathfrak{g}}$ M $s^{\hbar}s^{\Delta\varepsilon_{1}}$.

 \tilde{c} Arddy The resulting $-\Delta P_{\uparrow}$ on the strain change concrete he am $\frac{1}{2}$ $\frac{a}{r}$ けいの steel leve

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 652 × $-\frac{2F_1}{E_2A_0}$ $\frac{\Delta P_1 e^2}{E_C T_C}$ $-\frac{\Delta P_1 m}{E_5 A_5} (1 + \frac{e^2}{r^2})$

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aut corresponding change in the steel Force r.
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 $\frac{2}{3}$ o $\frac{\text{me}}{\text{r}^2}$ (1-m (1+ $\frac{\text{e}^2}{\text{r}^2}$) \div m ² (1+ $\frac{\text{e}^2}{\text{r}^2}$) 2

 $\begin{array}{c} 1 \\ 1 \\ 2 \end{array}$

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M change $\mathbf{\bar{u}}$ **De** Eirst given restresing $\pmb{\parallel}$ in the increase **IZ/IVZ** steel orde ζ $H₁$ Frame rame **DP** $\mathbf H$ where steel strain for any 707 $\pmb{\mathfrak{h}}$ steel excluding approximation. an the \mathbf{H} $\sum_{i=1}^{n}$ ene $\sum_{n=1}^{\infty}$ **Une** segment. live prestre forces summat **the** HH
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 $\frac{9}{10}$ Transfer

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D rt. \mathbf{u} Ĥ $70₁$ Atten harped tendons are used to get ansfe tores $rac{1}{2}$ pre-tensioned points the straight and has a constant force. н n
H connection is $\frac{0}{10}$ are
9 the two prestress applied to the concrete tendon is connected end points frames renoved at transfer. takes na
11 place $\frac{0}{2}$ prestressing th
C $\frac{1}{9}$ $\frac{1}{2}$ \mathfrak{c} desired eccentricity. the
S tendon. e
T $\frac{1}{2}$ e_h concentrated 11
N steel **Thus** prestreatng bedzeg sru₇ But someconcentendon **Gase** points.

which ζ gene g, zally has SOLIOS \overline{u} H.
M post-tensioned **Sancaco** $\frac{0}{10}$ a curved profile. aubrezas $\frac{1}{10}$ have frames the prestressing prestresing P constant force. Fhis steel profile is segments each steal tendon approximated $\frac{0}{n}$

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U C points of the present **The** \mathbf{a} concrete AB with typical of the assumption that m Eorce the
o steel prestressing $\pmb{\omega}$ **frame** implies interaction prestressing steel **Force** and the concrete takes element IJ each prestresing that $\frac{1}{2}$ between embedded. Eorce H. ehe which interaction 4 n
ha segments. u
11 $\pmb{\mathsf{p}}$ けえの Application prestressing prestressing place only steel end
D between points Fig. segment $\frac{0}{10}$ თ
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M element **bhe** angle coordinates between the
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F19. \bullet $\ddot{\bullet}$ Calculation \overline{a} $\frac{1}{2}$ Stress Relaxation

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စ $\frac{1}{2}$ element $\pmb{\times}$ axis joint and are
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O load vectors prestresing R_i and steel segment ¤، at joints AB. \mathbf{P} Then and Ū. t he $\frac{0}{n}$

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ਜ R_1 = $\langle R_1, j_1, R_2, j_2, R_3, j_7 \rangle$ = \blacksquare $58,11,1$ $R_{2\pm}$ R_3i^2 $\pmb{\text{M}}$ \leq $\frac{1}{\sqrt{2}}$ \leq $\frac{1}{\sqrt{2}}$ \leq $\frac{1}{\sqrt{2}}$ \leq $\frac{1}{\sqrt{2}}$ \times $\begin{bmatrix} x & y & y & z & z & z \\ y & y & y & z & z \end{bmatrix}$ (6.11) (11.9)

bhe $\pmb{\mathsf{p}}$ by multiplying the transformation matrix $\frac{1}{2}$ $(0.9, 0)$ These \mathbf{r} transfer total joint load vectors are transformed into the By assembling these load vectors for can be obtained. load vector for the structure Ispoip defined aue
P each element ი
0 coordinate by Eq. OISSTES Ū. œ \mathbf{a}

m $\pmb{\mathfrak{m}}$ quivalent joint rames けんの putss An identical procedure can be used to calculate the edescribed in section 6.4.2. steel for the second order analysis of unbonded loads due to correction forces u" the
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\mathbf{a} Stress Relaxation t"
J pusearearud Steel

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K 2 3 Ø œ developed xperimental data for a wide variety of prestressing **Cress** discussed Providence on the attreas relaxation in prestressing steel based the following equation for the in section 2.4. relaxation in prestresing stee Magura, Sozen calculation of the and $\frac{0}{1}$ **DUBUTOUS** Siesa steels. (901) Ë

 $\begin{array}{c} 19 \\ 0 \\ 0 \end{array}$ on
the $\begin{array}{c} 19 \\ 0 \end{array}$ $\bar{\mathbf{I}}$ $rac{1}{10}$ $rac{f}{f_y}$ = 0.55) ۰. $\frac{1}{2}$ $\ddot{\mathbf{v}}$ 0.55 (6.13)

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G $\pmb{\mathfrak{m}}$ tn. $\pmb{\alpha}$ \mathbf{r}^{\dagger} $t h e$ cause $\frac{\Omega}{\Omega}$ j. **Var** α various $\frac{1}{6}$ the initial $\frac{1}{6}$ puteatzous relaxation μ. pedo_r various $\mathbf{\hat{p}}$ \mathbf{u} procedure $\frac{1}{\mu}$ \bullet and ons. on e change $\frac{0}{5}$ after $\frac{1}{2}$ time example Φ the ore
o $\frac{0}{1}$ \bullet \blacksquare Prestre Hernande 'n Ghali, transf Ω cond tn. aepe. $\frac{1}{2}$ $\frac{1}{2}$ 计片 α $\mathbf{\dot{\alpha}}$ is the せいの rt
O m $\frac{1}{4}$ \mathbf{u} ndent to. \boldsymbol{u} $\frac{1}{2}$ m μ. \boldsymbol{a} $\overline{\mathbf{N}}$ $rac{1}{2}$ ø μ. into isodiy prest \mathbf{u} and
B 74 р
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11 load **1055** rt. \mathbf{a} Gamble ิ
ด anoun Tan sez: \bar{r} only \mathbf{p} ίŋ. count the
D an d ū \circ \mathbf{u} \mathbf{r} m rt ø tak ore $\frac{1}{2}$ $\pmb{\uparrow}$ ហ
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U ₹ \mathbf{r} Ņ. \mathbf{r} $\overline{\mathbf{r}}$ p. $\ddot{\mathbf{c}}$ alculate $\overline{\mathbf{r}}$ Te_T ous \check{p} ses laxation $\frac{1}{2}$ tim continuing ju. \sum_{m} $\overset{\circ}{\alpha}$ ά initial initial $\boldsymbol{\Phi}$ prestre dicps rt
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T Then, $\frac{1}{n}$ $T_{\rm D}$ $\Delta \tilde{f}_{r1}$ c a n time. \vec{c} calculat m
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លិ \vec{c} H $\ddot{\circ}$ f_s ₁ due from the $\frac{1}{2}$ Fig. Ω process \ddot{u} alculated applied $\frac{1}{\Omega}$ **basis** relaxation Afr2 $\frac{p}{1}$ 6.6, let \mathbf{r} similarly $\frac{1}{2}$
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6.7 Calculation $\frac{1}{2}$ Pres $\frac{1}{2}$ ssing Stee 1 Strains and ω ct $\overline{5}$ u |ທ
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 $\begin{bmatrix} a \\ b \\ c \end{bmatrix}$ Internal Element Forces |၁
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|0 **Prestress**

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∙ H₂H₂ $\frac{1}{2}$ joint i dedota points ά \mathbf{u} ta. \mathfrak{c}^{\star} egments **IGSS65, Che HEILS** こけれ **the** $\frac{1}{2}$ Eigure coordinates $\frac{0}{1}$ \circ which global coordinate axis, r₁, $F\ddot{1}g$. calculating the global coordinates $\pmb{\omega}$ rder けいの \vec{r} the $\ddot{\text{o}}$ iach
Ch **Daved** $\frac{6}{7}$ $\frac{1}{2}$ current \circ current length of efeag calculate shons is the the original global coordinates (X_o,Y_o). $(X'X)$ total displacement $\frac{0}{m}$ n, $\frac{0}{16}$ original angle procedure **Lie** n
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o points the current **Dasis** $\frac{1}{2}$ $\frac{1}{2}$ the **the** 计件 $\frac{0}{n}$

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S current

 $\frac{1}{2}$ Calculate **the Stress** corresponding \mathbf{c} $\boldsymbol{\omega}$ \mathbf{r} \mathbf{H} $\frac{1}{2}$ ene

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W resisting load vector follows zoz each element. ៸្អូ $\frac{\alpha}{6}$ $\frac{1}{2}$ Refer **Prestress** \mathfrak{a} Fig. can თ
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 $\frac{1}{2}$ $\frac{1}{2}$ \pmb{u} $5x$, y , $7y$, $2y$, $2y$, $2x^2$, $-2x^2$, $-2x^2$, $-2x$ (919)

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Ö $\frac{1}{\infty}$ Summary

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D **frames SOMe** u
U nonlinear additional prestressed concrete $\frac{1}{\alpha}$ frames similar time developed steps \mathfrak{c} dependent that which h
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Bended $\frac{1}{\tau}$ loading and and post-te **The** bna after u.
J analysis unbonded post-tensioned Prestressed Concrete nsioned ene transfer ۳.
۵ seructures performed $\frac{0}{n}$ DAGStream H_OH distuguishing **Services** three structures distinct $\ddot{}$ namely pre-tensioned **278** stages distinbefore, $\frac{0}{1}$

guished **HOT MOH** each $\frac{1}{9}$ type analysis $\frac{0}{4}$ **SHISPHERS BLCer** the
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10 the prestressing discussed unbonded structures is developed. the evaluation displacement A procedure is added $\frac{1}{2}$ post-tensioned $\frac{1}{2}$ directly steel account for $\frac{1}{2}$ Eieid approximate For premsioned or the ene including **Within** to the **GILINIDOSO** determination pue
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Π analysis SHARREN Pup the $\frac{0}{n}$ University the \mathfrak{a} procedures. present study $\frac{1}{2}$ Nere FORTRAN language of California, and written investigation verify $\frac{1}{2}$ $\begin{array}{c} \mathbf{1} \\ \mathbf{1} \\ \mathbf{0} \end{array}$ **VAA1** Berkeley. earlier ous H
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Dis program NTRUSS analysis $\frac{1}{2}$ Geometzic creep, R
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N $\frac{0}{16}$ shrinkage included. planar $\pmb{\omega}$ nonlineartty and plastic procedure for concrete **Stream-Buralli** and
S **Example** aging the trusses nd
a $\frac{0}{n}$ $4.5.2$ nonlinear time dependconcrete relatio ۳. w 3.9 incor **ana-**بر
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analyzed nonlinear lastic $rac{1}{2}$ material properties ζ **mez5ozd** analysis procedure eruis program. NFRAME **K**
RRA **Meze** written TOT assumed. planar \mathfrak{a} verify Frames. **Sxample** epp. Linearly 8.2.1 geometric 28.9 $\frac{1}{\sqrt{2}}$

prestressed Ω tions n
H procedures \mathbf{u} tor **the** these concrete programs ere
D programs incorporated **RCFRAME** frames, **are** and given in respectuely. TOT PCPRAME planar $\frac{1}{2}$ the Appendix. reinforced **Hice** present inqui analytiand instruc

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 $\frac{7}{2}$ Flow Chart $\frac{1}{2}$ the Programs RCFRAME $\begin{array}{c} \n\mathbf{a} \cdot \mathbf{n} \cdot \mathbf{d} \n\end{array}$ **PCPRAME**

 $\frac{1}{10}$ given ⋗ **bris** u.
U \blacksquare ene Elow Following chart $\frac{0}{10}$ page the programs **RCFRAME** and PORRAME

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FLOW CHART

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Fig. 8.1.c. Example 8.2.1 - Load vs. Midspan Stress Curve

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Fig. 8.2.b. Example 8.2.2 - Comparison of Midspan Deflection

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 ζ Experimental creep and shrinkage data are not reference 112. Ω assumed. **but** the ant $\frac{0}{1}$ detail ties, \rightarrow **Nete** È. ż, Fig. the experimental values of of concrete. ena secant the
D **Nitra** Material recommended by ACI in chapter $8.5 - 5 - 6$ and Fluck (113), the cross sectional properties and average The increase of the strength and modulus of time are shown modulus, E = 2835 ksi at σ = 1575 properties However, Formulas values $\frac{1}{2}$ The weight are used. $\frac{0}{m}$ in the earlier test on simple Committee 209 (56) and described in used in the Hor ur
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Fig. 8.5.a. Example 8.3.2 - Washa-Fluck Beam

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Fig. 8.5.c. Example 8.3.2 - Creep and Shrinkage Properties of Concrete

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Table 8.4. Example 8.3.2 and Theoretical Results \mathbf{L} **Tremmens** of Experimental

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Fig. 8.5.h. Example 8.3.2 - Comparison of Experimental and Theoretical Strains

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 $\ddot{\bullet}$ Comparison of Midspan Deflections and End Reactions

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Taable $8.8.$ Example 8.4,2 - Sumary of Results at Midspan

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Table 8.8 Example စြ
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- \bullet Live load for both unbonded beams is 1,0pp. Unbonded beam is the strinkage data as bonded beams and with the same shrinkage data as a bonded beams and with the same same and the 7-yea.
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Conded beams.
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Fig. 8.9.c. Example 8.4.3 - Comparison of Midspan Deflection for Bonded Beams

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Analysis $\frac{1}{n}$ |a Pensioned Column

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Stress-Strain Curve:

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- (1) NN : Material Nonlinearity
- (2) GN : Geometric Nonlinearity
- (3) NJ : Number of Joints
- (4) NE : Number of Elements
- (5) NCL: Number of Concrete Layers
	- (6) MSL: Number of Reinforcing Steel Layers
- (7) NPS: Number of Prestressing Steel Segments
- (8) NTS: Number of Time Steps
- (9) NLS: Total Number of Load Step
- (10) NIT: Number of Iterations per Load Step
- (11) CP : Central Processor Time
- (12) PP : Peripheral Processor Time

Summary of the Computer Time and Cost for the Examples Table 8.11.

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