(JZS) Journal of Zankoy Sulaimani, September 2007, 9 (1) Part A {69-79}
گۆڤاری زانكۆی سلێمانی ئەیلول ٢٠٠٧ بەرگ ٩ (١) ژمارە ١ بەشی A لاپەرە {٦٩-٧٩}

Nonlinear Analysis of High Strength Concrete Frames under Cyclic Loading

Abdulkareem Darweesh Mahmood

Civil Engineering Department College of Engineering University of Salahaddin,Hawler
Kurdistan Region/Iraq

Abstract

A computer program has been developed to predict the behavior of high strength reinforced concrete frames subjected to cyclic loading. The computer program used to simulate the numerical solution is coded in basic language using effective stiffness method with successive iterations. The nonlinear cyclic behavior of high strength concrete and steel was considered using the layered approach for section analysis. Dumping ratio of such frames was also evaluated showing the advantage of HSC for energy absorption.

Keywords:- high strength concrete, nonlinear analysis, frames, cyclic loading.

Introduction

High strength concrete has become widely accepted practically in all continents, also there are an increase amount of researches on this material . The applications of HSC were in the areas of long-span bridges and high rise buildings. Structures may be under cyclic loading in different situations such as; earthquake loading, bridges under repeated loading, cyclic wind loading, cyclic temperature variation as in nuclear reactors or industrial structures supporting cyclic loading instruments.

The high compressive strength of the HSC is due to the low water/cement ratios that can be used and also the effect of the microsilica added on the microstructure of the paste [1],superplactisizers used to increase workability which was reduced by low W/C ratio.HSC is defined as concretes with max. compressive strengths greater than the conventional concretes.

Many researches focused on the behavior of the HSC as a material bytesting it experimentally or proposing an analytical or empirical models such as; Ngab etal [2],Xie etal[3],Irvani [4],Wiegrink etal[5],Khan etal[6],Samman etal[7],Zia etal[8] and ACI committee363 [9].Mo and Wang [10],Yeh etal [11] performed tests on reinforced concrete columns under seismic loading. Girard and Bastien [12] used finite element bond slip model for concrete columns under cyclic loading. Lee and Pan [13] proposed computational beam-column finite element model for the analysis of composite steel-reinforced concrete members, Bugeja, etal.[14] and Montesinos and Wight [15] performed tests on composite steel-reinforced concrete structures under seismic loading ,ACI-ASCE committee 441 [16]
discussed the behavior of HSC columns subjected to combined axial and bending moments in terms of variables related to concrete and transverse reinforcement, the behavior under seismic performance of HSC columns were also considered . Tan etal [17] tested reinforced concrete deep beams with compressive strengths of 41-59 MPa. Test results
were compared with ACI building code provisions.
Muhammad,A.H.[18] conducted tests on high strength fiber reinforced concrete corbels under monotonic and cyclic loading. Variables considered were volume fraction of fibers, shear span-to-depth ratio and volume of stirrups. Varma etal,[19] performed tests on high strength square

Email:-abdmqazi@yahoo.com

concrete-filled steel tube beam-columns.

Reinforced concrete frames under cyclic loading were studied by many researchers: Darwin and Pecknold [20] used a four nodded isoparametric quadrilateral finite element to predict the behavior of such frames, Papadopoulos and Karayannis[21,22] used the net work model to study the behavior of such frames under seismic loading.

The present study considers the behavior of one bay one story reinforced HSC frames subjected to cyclic loading.

Material models

To predict theoretically the response of a structure properly, material constitutive relations are needed. It was observed [23] that the monotonic uniaxial behavior of normal concrete is the envelope for the cyclic behavior, according to this observation the uniaxial monotonic behavior of HSC is considered as an envelope for its behavior under cyclic loading.

In this research the monotonic stress-strain behavior of different HSC as shown in figure(1) [9], were adopted. To simulate this behavior as a subroutine in a computer program,

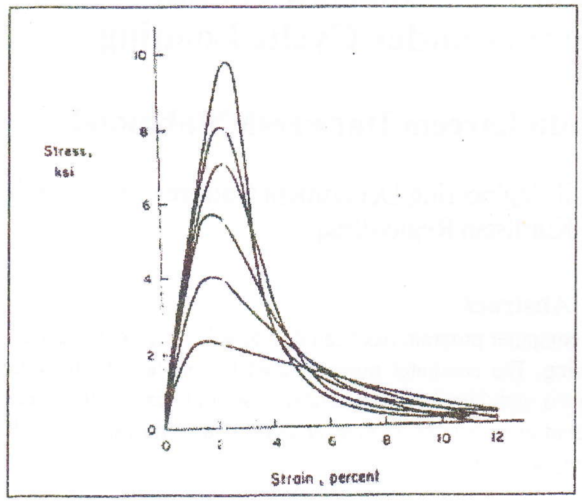
the curves were taken as a data points and a polynomial curve was fitted for each HSC, for example figure(2) shows one of these polynomials, which in general are in the form of:

$$Y = a + b*X + c*X^2 - d*X^3 + e*X^4 - f*X^5 \quad \ldots(1)$$

Where Y: is the normalized stress (stress/ maxi mum compressive or peak stress).

X: is the normalized strain (strain / strain under peak stress).

a,b,c,d,e and f: constants varied with the max.



Figure(1); Stress-strain curve for different

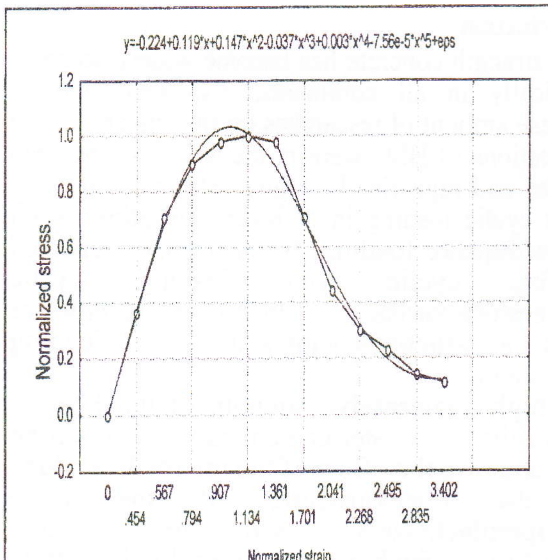
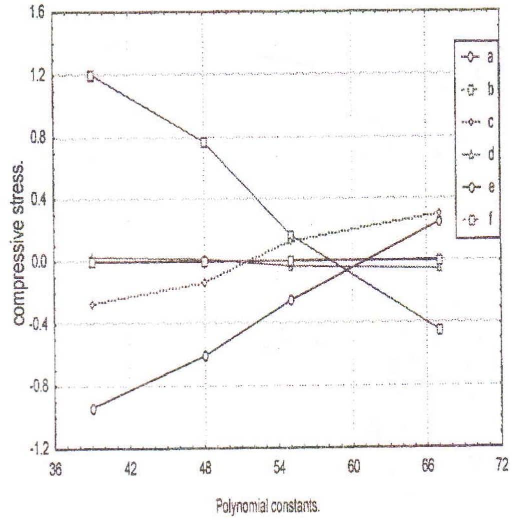


Figure (2) Polynomial fitting for a HSC behavior.



Figure(3) polynomial constants variatin with max. compressive strength..

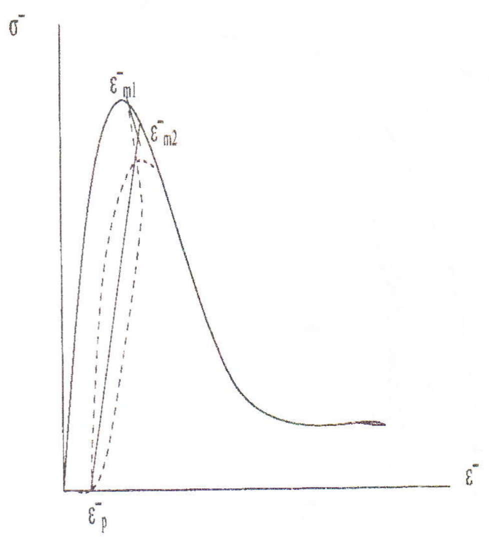


Figure (4) cyclic behavior of concrete [24].

compressive strength of HSC, figure(3).

Four different max . compressive strengths HSC were considered (39, 48, 55 and 67 MPa).These polynomial curves were considered as an envelope for the cyclic behavior under compression .Concrete behavior under tension was modeled as a linear path with a modulus of elasticity equals to the nominal modulus of elasticity in compression, till the maximum tensile strength (f_t) is reached, after which the concrete strength in tension is dropped to zero.

For the cyclic behavior, unloading and reloading curves has the curved paths shown in dotted lines in figure (4), [23]. In the present study a linear mean path as indicated was used which was adopted previously for the normal concrete [24].For each unloading strain (ε_m) the plastic strain ($\bar{\varepsilon}_p$) is computed from the following equations [23]:

$\bar{\varepsilon}_p = .055\,\bar{\varepsilon}_m + 0.127(\bar{\varepsilon}_m)^{3.1}$ for $\bar{\varepsilon}_m \leq 2.2$ ....(2)

$\bar{\varepsilon}_p = 1.584 + (\bar{\varepsilon}_m - 2.2) * 0.2675$ for $\bar{\varepsilon}_m > 2.2$ ....(3).

After reloading,the reloading strain $\bar{\varepsilon}_{ml}$ for each unloading strain is:

$\bar{\varepsilon}_{ml} = 1.11 * \bar{\varepsilon}_m$ .... (4)

For reinforcing steel, a uniaxial stress- strain relationship known as Menegotto and Pinto model was adopted, figure (5) ,[23]. Where the stress strain curves of different cycles lie within the two parallel lines A-B and A′-B′ defined by the monotonic curve and passing through the points (ε_{so}, σ_{so}) and ($-\varepsilon_{so}$, $-\sigma_{so}$). The initial slope of the curves is the same for monotonic curve E_s, each half cycle is modeled by:

$\bar{\sigma} = (1-b)\left((\bar{\varepsilon}/(1+\bar{\varepsilon}^{R})^{1/R}\right) + b\,\bar{\varepsilon}$ ....(5)

Where $\bar{\sigma}$ and $\bar{\varepsilon}$: are the normalized stress and strains respectively and b: is the slope of the two lines A-B and A′-B′.

For curves after the first load inversion:

$\bar{\sigma} = \{(\sigma_s - \sigma_{In}) / (\sigma_{Kn} - \sigma_{In})\}$ ....(6)

$\bar{\varepsilon} = \{(\varepsilon_s - \varepsilon_{In}) / (\varepsilon_{Kn} - \varepsilon_{In})\}$ ....(7)

where the point (ε_{In}, σ_{In}) is the start of the nth inversion , (ε_{Kn}, ε_{In}) is the intersection of the two lines shown in figure (5). The exponent (R) varies

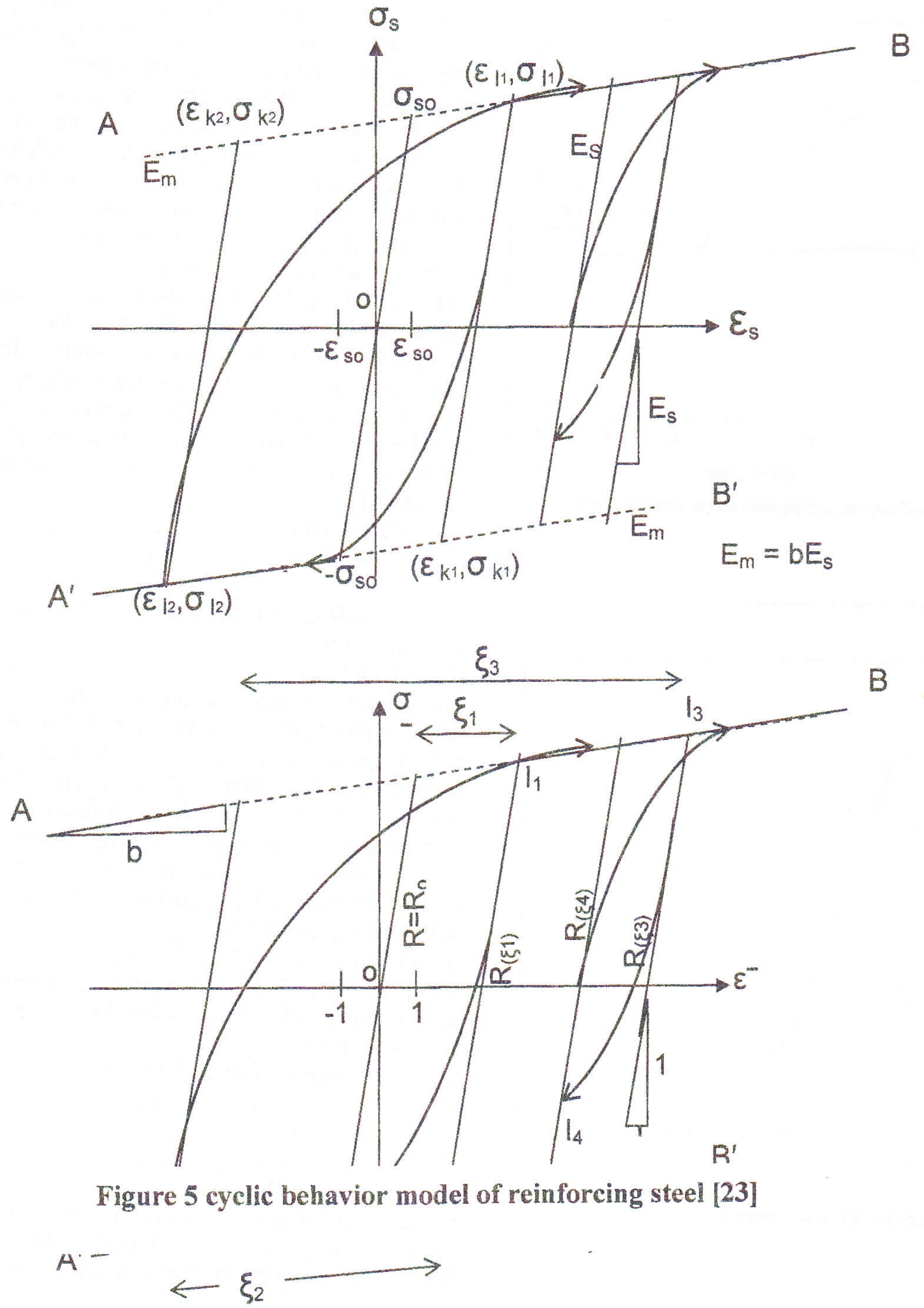


Figure 5 cyclic behavior model of reinforcing steel [23]

after the first inversion to represent the Bauschinger effect: $R_{(\xi_n)} = R_o - \{ (A_1 \xi_n) / (A_2 + \xi_n) \}$ ....(8)

R_o, A_1, A_2 are parameters for best fitting, and ξ_n is the plastic deformation in a half cycle. The best fitting values as recommended by Menegotto and Pinto: $R_o = 5.3$, $A1 = 3.446$, $A2 = 1.766$ and $b = 0.015$.

Section analysis

Each section at the ends of sub-members was analyzed by dividing it into imaginary concrete layers and reinforcement bar elements, figure (6). Plane sections were assumed to remain plane after bending, also perfect bonding between concrete and steel was assumed.

The longitudinal strain in each concrete or steel layer was calculated as a function of the top and bottom fiber strain. Internal axial force and bending moment was calculated according to strain distribution, were the strain in each layer was assumed constant through layer depth.

Maximum and minimum top and bottom fiber strains were assumed first, then the bisection method was used to correct the top and bottom fiber strains, this is done by comparing the external axial force and bending moments at each section with the internal axial force and bending moments calculated from the assumed strain distribution. The top fiber strain was adjusted according to external and internal axial force comparison, while the bottom fiber strain was adjusted according to external and internal bending moment's comparison. Figure (7) shows a flow chart for the subroutine of the section analysis process.

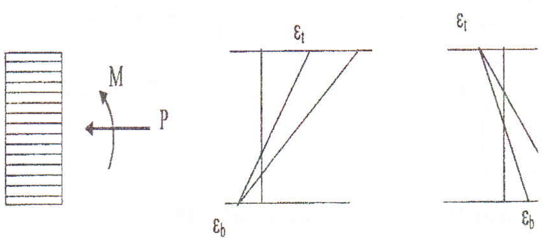


Figure (6): Section analysis by layering approach.

Frame analysis

Each frame was divided into sub-members figure (8), direct stiffness method was used for frame analysis. First uncracked section with linear and initial elastic range was used, axial force, shear force and bending moments at each section or member ends were determined. As a result the strain at the center lines (ε_{cl}) ,and the curvatures (φ) is known at each section.

Effective axial stiffness (Ae) and effective flexural stiffness(Ie) at each section was calculated as:

$Ae = AF / (\varepsilon_{cl} * Ecn)$ ....(9)

$Ie = BM / (\varphi * Ecn)$ ....(10)

Where Ecn; is the modulus of elasticity of concrete. For each member an equivalent effective axial stiffness (Aee) and flexural stiffness (Iee) were calculated using interpolated values of the two member ends[25]:

$Aee = Ao[1 - \{ 0.5*(1 - Ae1/Ao)^5 + 0.5*(1 - Ae2/Ao)^5 \}^{1/5}]$ ....(11)

$Iee = Io[1 - \{ 0.5*(1 - Ie1/Io)^5 + 0.5*(1 - Ie2/Io)^5 \}^{1/5}]$ ....(12)

Where: Ao and Io are the uncracked section area and moment of inertia. The average of the current calculated stiffness and the previous stiffness foreach member were used in the stiffness matrix. The process of recalculating axial and flexural stiffness were continued until these values converges. Figure (9) shows a flow chart of the computer program used for frame analysis.

Applications

A frame with details and dimensions shown in figure (8) was solved under cyclic loading by the computer program presented before ,steel areas are :As1=1000 mm^2 and As2=1500 mm^2. Figure (10) shows the cyclic behavior for a normal concrete with compressive strength 35 MPa, HSC1and HSC2 with max. Compressive

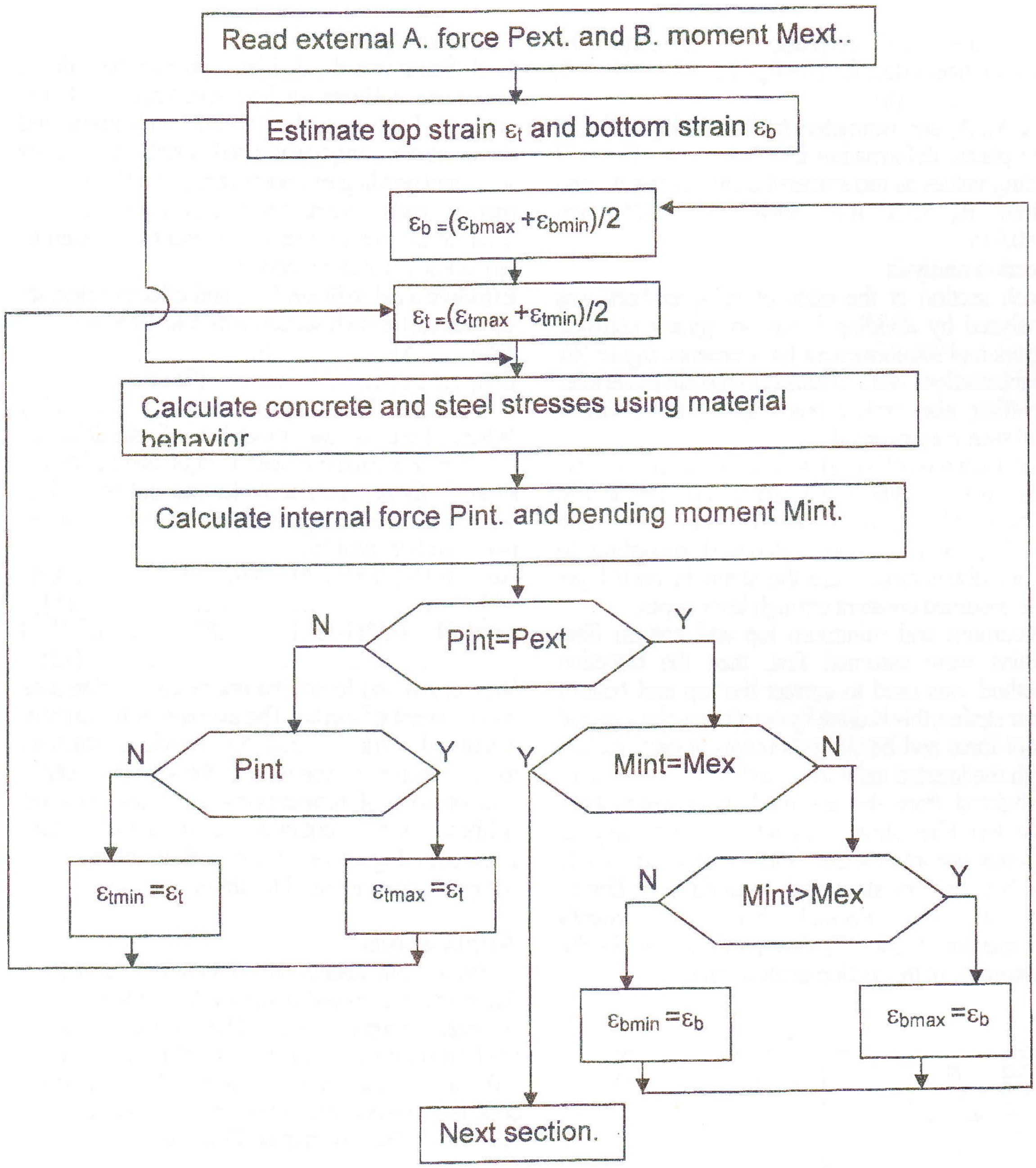


Figure 7: flow chart for the subroutine of nonlinear section analysis.

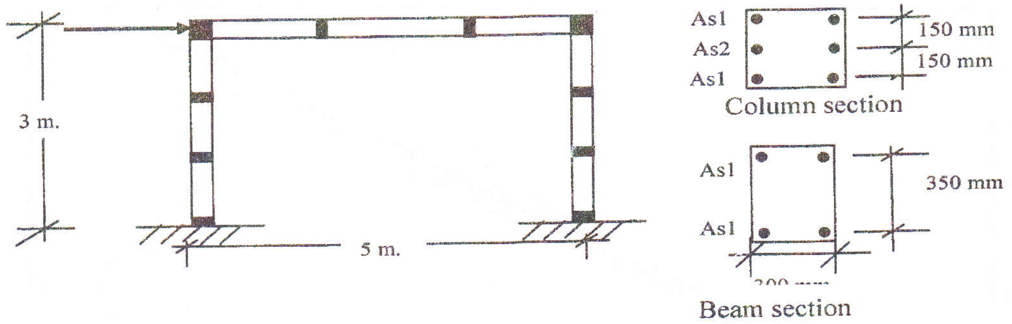


Figure (8): Frame detailing and division into sub-members.

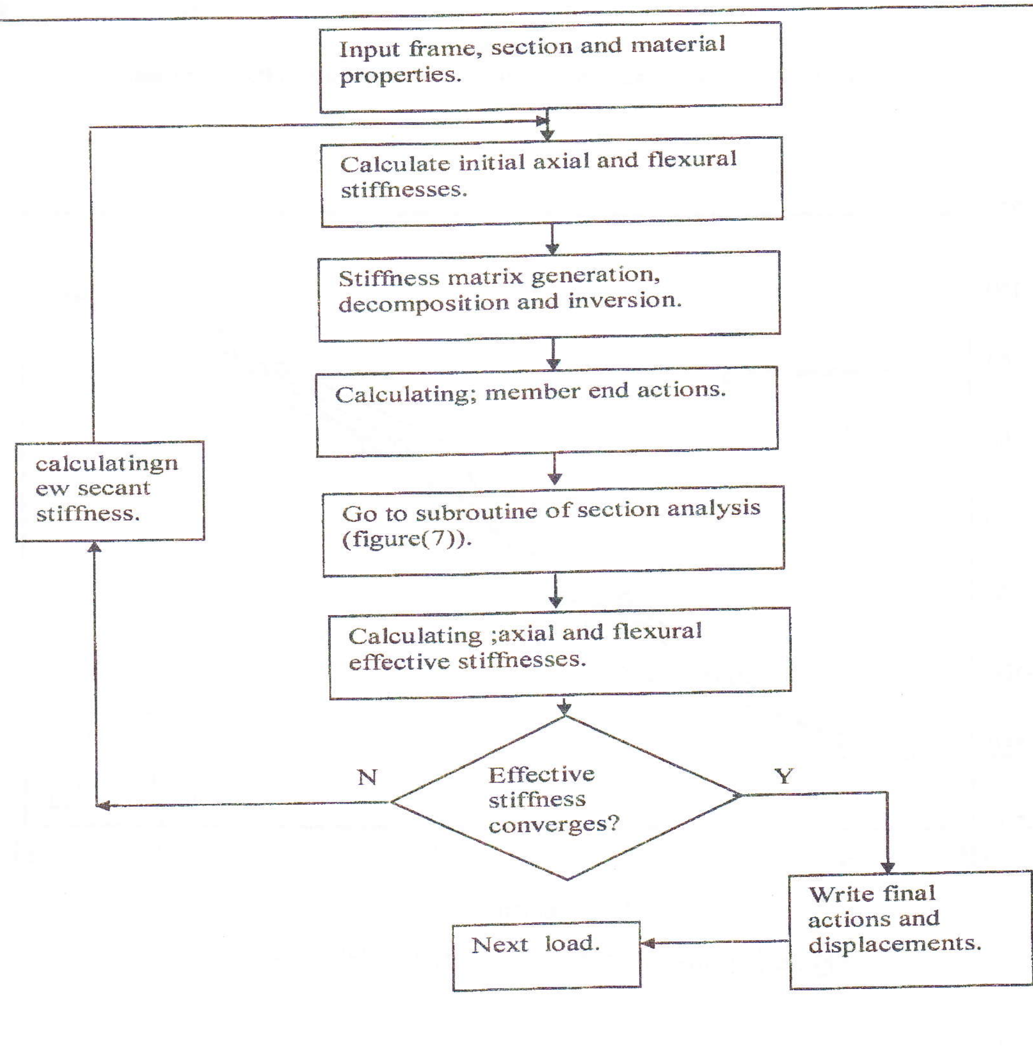


Figure (9): flow chart for nonlinear frame analysis.

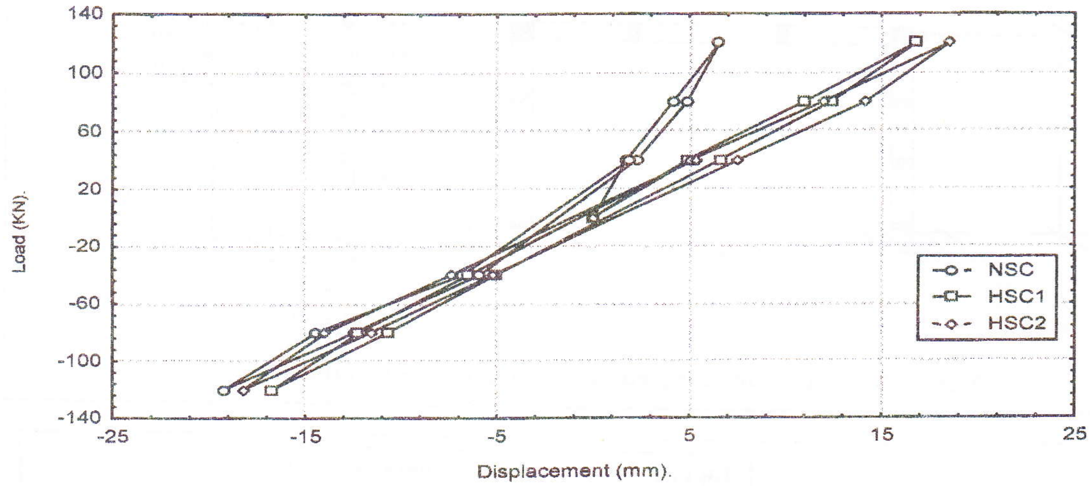


Figure (10) load displacement curves for NSC and HSC frames.

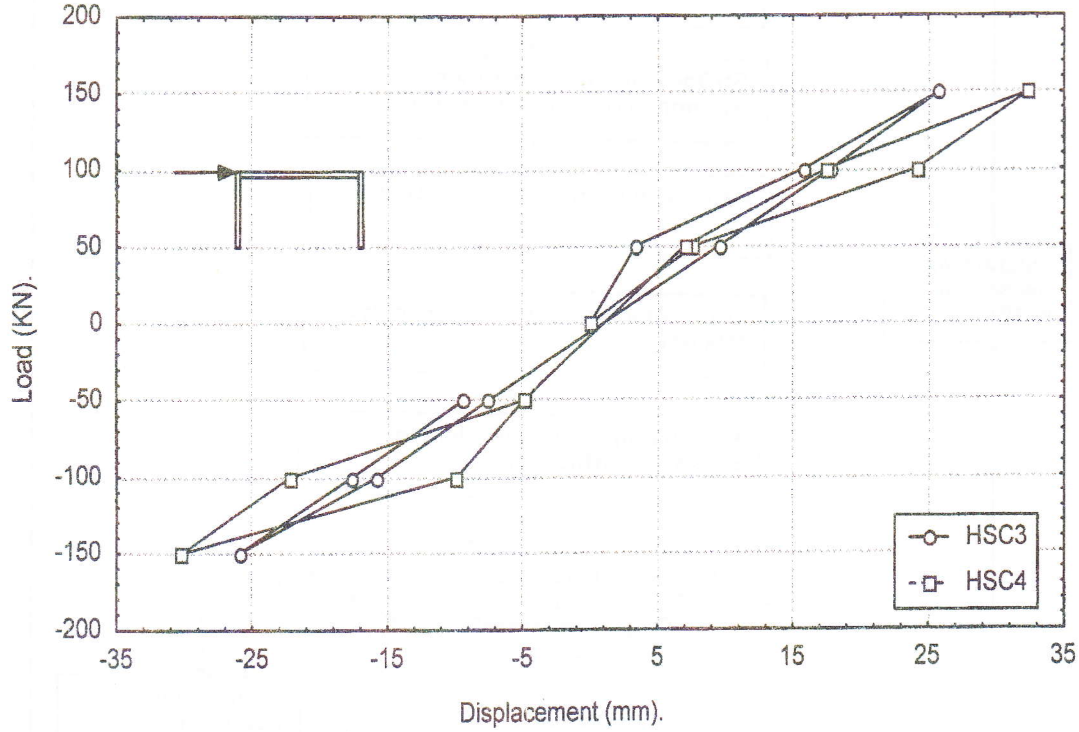
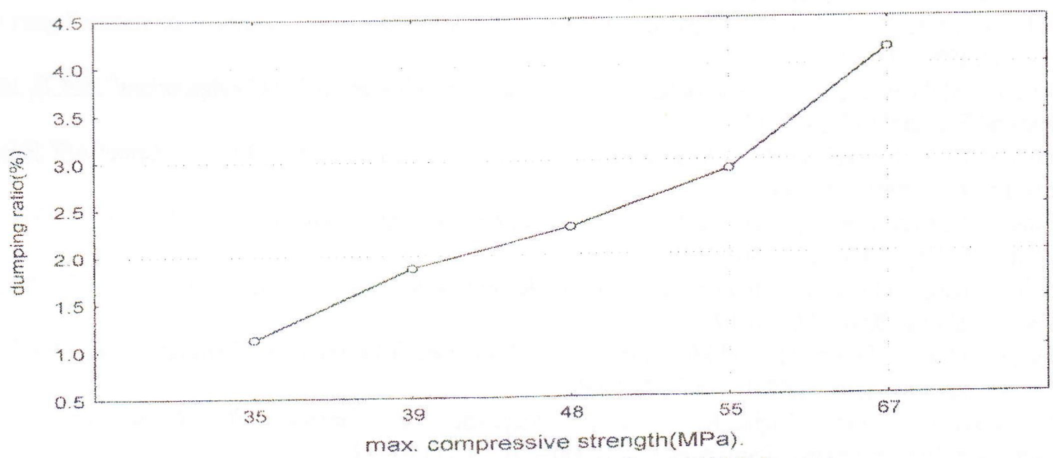


Figure (11) load displacement curve for HSC frames.

Figure (12) enclosed areas for dumping evaluation [26].



Figure(13) dumping ratios for different HSC frames.

trengths 39 and 48 MPa respectively. Figure (11) shows the behavior of HSC3 and HSC4 with maximum compressive strength 55 and 67 MPa respectively. The dumping ratio for a frame through a load cycle is given by [26]:

Dumping ratio= $(1/2\pi)(Wd / Ws)$

Where Wd; is the area enclosed in the hysteretic loop, and Ws; the area of the two triangles corresponding to the spring action ,figure(12).the dumping ratio for frames with different HSC strengths is shown in figure (13).

Conclusions

1- the proposed polynomial for HSC behavior seams to be reliable and simple , the polynomial constants can be interpolated or extrapolated for other HSC .

References

1- Gani, M.S.J : Cement and Concrete. 1st edition , Chapman& Hall, London,**1997**.

2- Ngab,Alis, Slate,F.O. and Nilson,A.H." *Microcracking and Time-Dependent Strains in High Strength Concrete*". ACI Journal,Proceedings, **1981,** 78, 4,., .262-268.

3- Xie,J. , Elwi,A.E. and MacGregor,J.G." *Mechanical properties of High-Strength Concretes Containing Silica*". ACI Materials Journal, **1995**, 92, 2, 135-145.

4- Irvani,Said"*Mechanical Properties of High Performance Concrete* ".ACI Materials Journal, 1996,93, 5, 416-426.

5- Wiegrink,K., Marikunte,S. and Shah,S.P. " *Shrinkage Cracking of High-Strength Concrete*",ACI Materials Journal,. **1996,** 93, 5, 409-415.

6- Khan, A.. A.., Cook,W.D. and Mitchell,D."*Tensile Strenght of Low,Mediaum and High Strength Concretes at Early Ages*",ACI Matreials Journal, **1996**, 93, 5,. 487-493.

7- Samman,T.A., Mirza,W.H. and Wafa,F.F. " *Plastic Shrinkage Cracking of Normal and High-Strength Concrete: A Comparative Study*".ACI Materials Journal, **1996**, 36-40.

8- Zia,P. , Ahmed,S. and Leming,M."*High-Performance Concrete*", A State-of-Art Report(1989-1994). Papare No. FHWA-RD-97-030. U.S. Department of Transportation Federal Highway Administration.

9- ACI Committee 363 "' *State –of-Art Report on High-Strength Concrete*".ACI Journal, Committee Report no. ACI 363R-84. **1984,** 364-411.

10-Mo,Y.L . AND Wang,S.J. "*Seismic Behavior of RC Columns with Various Tie Configurations*" ASCE, Journal of structural Eng. **2000.**126,.10,.1122-1130.

11-Yeh,Y.K.,Mo,Y.L. and Yang,C.Y."*Seismic Performance of Rectangular Hollow Bridge Columns*"ASCE,Journal of Structural Eng. **2002**,128,., 60-68.

12- Girard, Claire and Bastien, Josee "Finite *Element Model for Concrete Columns under Cyclic Loads*".ASCE, Journal of Structural Eng. **2002,**128, ,.1502-1510.

13-Lee,Tai-Kuang and Pan,D.E."*Analysis of Composite Beam-Columns under Lateral Cyclic Loading*"ASCE,Journal of Structural Eng. **2001**,127, 186-193.

14-Bugeja,Michael N.,Bracci, J.L. and Moore Jr.,"*Seismic Behavior of Composite RCS Frame Systems*"ASCE,Journal of Structural Engineering, **2000**,126, 4, l, ,.429-436.

15-Montesinos,G.P. and Wight,J.K." *Seismic Response of Exterior RC Column-To-Steel Beam Connections*"ASCE,Journal of Structural Eng., **2000**, 126,.10,.1113-1121.

16-.ACI-ASCE Committee 441" *High-Strength Concrete Columns: State of the Art*",ACI Str.Jr. , 1997,.323-335.

17-Tan,Kang-Hai, Kang,Fung-Kew, Teng,Susanto and Guan,Lingwei." *High-Strength Concrete Deep Beams with Effective Span and Shear Span Variation*". ACI Structural Journal, **1995**, 92,4, -., 395-405.

18-Muhammad, Ahmed H. Behavior and Strength of High-Strength Fiber Reinforced Concrete Corbels Subjected to Monotonic or Cyclic(Repeated) Loading. Ph.D.Thesis, University of Technology, Baghdad, **1998.**

19-Varma ,A.H. , Sause,R. and Lu,L.W."*Experimental Behavior of High Strength Square Concrete-Filled Steel Tube Beam-Columns*",ASCE,Journal of Structural Eng**.**, **2002**,128, 3,.309-318.

20-Darwin, D. and Pecknold, D.A."Analysis of CyclicLoading of Plane R/C structures".Computers and Structuers, **1977**, 7, 137-147.

21-Papadopoulos,P.G. and Karayannis,C.G."Nonlinear Seismic Analysis of R/C Frames by Network Models".Pacific Conference on Earthquake Engineering,New Zealand,**1987.**

22-Papadopoulos,P.G. and Karayannis,C.G."Nonlinear Seismic Analysis of R/C Frames by Network Models".Computers and Structures,**1988** , 28,.4, ,.481-494.

23-Al-Sulayfani, Bayar J. : Contribution a l etude du Comportment des Ossatures en analysenon-lineaire globale. Docteur de l universite de Nantes, Specialite genie civil, 1986.

24-Mahmood , A .D.: Nonlinear Analysis of Reinforced Concrete Frames under Cyclic Loading. M.Sc. Thesis University of of Mosul, **1989.**

25-Vecchio, F.J. "*Nonlinear Analysis of Reinforced Concrete Frames Subjected to Thermal and Mechanical Loads*". ACI Str. Jr..**1987**,. 492-501.

26-Clough, Ray W. and Penzien,Joseph : Dynamics of Structures.", McGraw-Hill Kogakusha LTD, **1975**,634. .

شیتەڵکردنی ناهێڵی یەیکەری کونکریتی بەرزە هێز لە ژێر باری خولگەیی.

عبدالکریم دەرویش محەممود

بەشی تەلارسازی/کۆلێجی ئەندازیاری /زانکۆی سلێمانی

پوختە:

لەم توێژینەوەیەدا پرۆگرامێکی کۆمپیوتەر دانرا بۆ پێشبینی کردنی هەڵسوکەوتی پەیکەری کونکریتی بەرزە هێز لە ژێر باری خولگەیی. پرۆگرامەکە بە زمانی بەیسک ئامادە کراوە.

ڕێگای تونەی کاریگەر بەکار هێناوە لەگەڵ دووبارە کردنی لە دوایەک . هەڵسوکەوتی نا هێڵی بۆ کونکریت و پۆلا ڕەچاوکرا بە هۆی بەکارهێنانی ڕێگای دابەش کردنی ڕوبەری هەر برگەیێک بۆ چەند چین . بە ڕەچاو کردنی ڕێژەی خاوبون چاکەی بەکارهێنانی کونکریتی بەرزە هێز بۆ هەڵمژینی ووزە دیارکرا.

التحليل اللاخطي للهياكل الخرسانية عالية القوة تحت الاثقال الدورية

عبد الكريم درويش محمود

قسم المدني /كلية الهندسة/جامعة صلاح الدين اقليم كوردستان-العراق

الخلاصة

تم اعداد برنامج على الحاسوب للتنبؤ بتصرف الهياكل الخرسانية من الخرسانة عالية المقاومة المعرضة الى اثقال دورية. تم اعداد البرنامج الذي يمثل الحل العددي بلغة البيسك. استعمل في البرنامج طريقة الصلادة المؤثرة مع التكرار المتوالي .تم اخذ التصرف غير الخطي للخرسانة والحديد بنظر الاعتبار من خلال اعتماد طريقة تقسيم المقاطع الى طبقات . يبين البحث افضلية استعمال الخرسانة عالية المقاومة في امتصاص الطاقة من خلال احتساب نسبة الخمود.

Received 31/5/2005 Accepted 23/8/2005

وەرگرتن لە ٢٠٠٥/٥/٣١ داوپەسەند لە ٢٠٠٥/٨/٢٣ز.