Center for Civil Engineering
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USER'S MANUAL FOR LZAK-C64

A Computer Program to Implement
the Q-Model on Commodore 64

by

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ABSTRACT

A simple nonlinear model (called the Q-Model) for seismic displacement history analysis of reinforced concrete plane frames was implemented on a Commodore 64. This manual presents a brief description of the model (see the Appendix) and outlines the procedure to use the model. It is assumed that the user is familiar with the derivation of the properties of the Q-Model. Two examples are presented to demonstrate the input preparation and the resulting output.

INTRODUCTION

The Q-Model is a simple analytical tool to estimate the lateral displacement history of relatively uniform reinforced concrete frame and frame-wall structures subjected to base accelerations. The model has been found to be useful in calculating the response of multi-story structures for a variety of earthquakes and evaluating the seismic performance of the structures. To make the model available to users with access to low-cost microcomputers, the Q-Model was recently implemented on a Commodore 64 with six built-in earthquake records. The purpose of this manual is to explain the application of the computer model.

The program user is assumed to be totally responsible for the application of the program and the use of its results.

METHODOLOGY

The development and application of the Q-Model has been demonstrated in detail on a variety of building structures in References 1-8. A brief description of the model is presented herein for the sake of completeness.

The Q-Model idealizes a planar reinforced concrete building structure by an oscillator shown in Fig. 3 of the Appendix. The mass and height of the equivalent system are determined based on the masses of the multistory structure lumped at the floor levels, and the floor heights measured from the base [1,2]. Energy principles are used in finding the equivalent mass and height. The base spring is a nonlinear spring representing the overall lateral stiffness characteristics of the multistory structure. A bilinear primary curve is necessary which shows the base moment in terms of horizontal displacement at the equivalent height. To determine this curve a nonlinear static analysis [1], or a limit analysis and a linear static analysis of the structure [7] is carried out. To characterize the stiffness

variations of the structure during the earthquake, a simple hysteresis model, called Q-hyst, is incorporated in the program [1,5].

The reduction in stiffness due to gravity effect is taken into account. Using the instantaneous stiffness and a mass-dependent damping coefficient, the equation of motion is formulated for the equivalent system in incremental form and integrated using Newmark's β method [9] with $\beta =$ 0.25. This β corresponds to a constant acceleration over each time interval. For each time increment, the displacement is calculated and stored for plotting the response history.

PROGRAM LZAK-C64

LZAK-C64 is the Commodore 64 version of a program called LARZAK which was developed to implement the Q-Model [10] on CYBER main frame computers. The input to LZAK-C64 is short and is prepared interactively.

Currently, a data bank of six well-known earthquake records is incorporated in the program. The acceleration records consist of the first fifteen seconds of the following earthquakes:

      El Centro 1940, NS

      El Centro 1940, EW

      Taft 1952, S69E

      Bucharest 1977, NS

      8244 Orion Blvd. 1971, NS

      Pacoima Dam 1971, S16E

The first five records are part of LZAK-C64. The record for Pacoima Dam is stored on a sequential file and read by LZAK-C64 automatically, if the user specifies this earthquake.

The response histories are stored and plotted on the Commodore printer (VIC 1525) in the form of character plotting, or on the Commodore plotter

(Vic 1520) as a continuous curve. The subroutine to plot the response on the VIC 1525 was included for the users who have access to VIC 1525 but not to VIC 1520. No labeling capabilities are provided in the plot on VIC 1525. While the quality of the plot on the VIC 1525 may be acceptable for a visual evaluaton of the shape of the response, for a better quality response history and appropriate labeling, the VIC 1520 is recommended. More information about the program may be found in the Appendix.

INPUT PREPARATION

The input to LZAK-C64 is provided interactively. The input data describe the equivalent SDOF system and the input earthquake.

1.   PROJECT TITLE?

Any alphameric string to identify the input. This title is not processed in any way, and it is only used as a heading in the output. Maximum 30 characters.

2.   UNITS?

Units of force, length, and time are given in this part in the first 30 spaces. Similar to the project title, the units are not processed by the computer and are displayed in the output for user's information. Consistent units are to be used. See Item 16 for restrictions on units of input data.

3   DAMPING COEFFICIENT?

A mass-dependent damping is used in the program. The damping coefficient is multiplied by the equivalent mass and by the instantaneous velocity to determine the damping force. To determine the damping coefficient, use

Damping Coefficient = $2\xi\omega$

in which ξ = damping factor (usually from 0.02 to 0.1)

$\omega = M_y / (L_e D_y M_e)$

M_y = yield moment (moment at the break point of the primary curve)

L_e = equivalent height

D_y = yield displacement (displacement at the break point of the primary curve)

M_e = equivalent mass

4.   <u>EQUIVALENT AND TOTAL MASS?</u>

(See the Appendix)

5.   <u>GRAVITY ACCELERATION?</u>

This parameter is needed to determine the reduction in stiffness due to the P-Δ effect.

6.   <u>EQUIVALENT HEIGHT?</u>

(See the Appendix)

7.   <u>FACTOR TO NORMALIZE RESPONSE?</u>

This factor is multiplied by the displacement response of the equivalent mass to determine the response at any floor. To compute the factor for any floor, divide the normalized displacement at that floor (parameter P, in Fig. 2 of the Appendix) by P at L_e.

8.   <u>YIELD AND ULTIMATE MOMENT?</u>

(See the Appendix)

9.   <u>YIELD AND ULTIMATE DISPLACEMENT?</u>

(See the Appendix)

10.   <u>EARTHQUAKE CODE?</u>

The following code numbers are assigned to the earthquake records in LZAK-C64.

Code	Record	Maximum*
1	El Centro NS	3,417
2	Orion	2,500
3	Taft S69E	1,759
4	Bucharest	20,175
5	El Centro EW	2,101
6	Pacoima	11,481

*See input item 12.

11.　DURATION OF EARTHQUAKE?

Up to 15 seconds of input earthquake may be specified. Use a whole number from 1 to 15.

12.　ACCELERATION AND TIME MULTIPLIER?

The acceleration multiplier is used to scale the intensity of the input earthquake. The multiplier is determined based on the maximum acceleration in each record as listed under item 10, and the desired peak ground acceleration. A time multiplier of one is ordinarily used for the analysis of full-scale structures. However, if the structure is of small scale, an appropriate time multiplier is used to account for differences between the period of the small-scale and full-scale structures.

13.　TIME INTERVAL FOR NUMERICAL INTEGRATION?

The time increment at which the earthquake data are provided is 0.02 second. This time is scaled by the time multiplier explained in item 12. If the time interval for numerical integration exceeds the product of 0.02 and the time multiplier, the program will reduce the time interval to 0.02 * time multiplier. While this limit may be appropriate for many cases, the user may choose to use one-half or one-fourth of the maximum limit for a more refined analysis. In any

case, the time interval should be chosen such that the total number of response points will not exceed 1500.

14. RESPONSE PLOT REQUIRED?

The response plot may be obtained on either a VIC 1525 printer (for a rough plot) or a VIC 1520 plotter (for a smooth curve plotted by a ballpoint pen, with appropriate labeling). Type "Y" or "N" as desired.

15. ON PLOTTER OR PRINTER?

Use only if a response history is to be plotted. Device 1 is assigned to VIC 1525 and 2 is assigned to VIC 1520.

16. MAXIMUM RESPONSE IN PLOT?

Use only if a response history is to be plotted on VIC 1520. The question is asked after the response maxima has been determined and shown on the output. Round up the maximum displacement and use. The value given here should not have more than two characters; other-wise, the labelings for the time axis will be misplaced. Select units of the input data with this requirement in mind. No restric-tions apply if the response is not to be plotted on VIC 1520.

17. RESPONSE AXIS LABEL?

This is used only if a response history is to be plotted on VIC 1520. Strings of up to 15 alphameric characters (including blanks) may be used.

NUMERICAL EXAMPLES

To Illustrate the use of LZAK-C64, two numerical examples are presented in this section. A brief description of each example is provided below, followed by the input and output for each case.

Six-Story Frame

This is a full-scale structure analyzed for the first 15 seconds of the north-south component of the 1940 El Centro record, normalized to have a maximum input acceleration of thirty-five percent of gravity. Because the structure is of full scale, a time multiplier of one is used. The response history plot was obtained on a VIC 1520.

Structure MF1

This is a small-scale structure which had been used in previous studies of the Q-Model [1]. The structure was analyzed for the first 15 seconds of the north-south component of the 1940 El Centro record, with the peak acceleration scaled to forty percent of gravity. The units used in this example were kilonewton and millimeter to obtain a maximum response which, when rounded up will consist of two characters. This requirement had to be met because the response history was to be obtained on a VIC 1520.

Because the structure had a fundamental vibration period of approximately forty percent of that for comparable full-scale structures, an earthquake time multiplier of 0.4 was used. Note that, even though a time interval of 0.02 was specified for numerical integration (see the input), the program actually used 0.008 sec. which is the product of 0.02 (time increment for the input earthquake data) and 0.4 (see the output).

The response history was plotted on a VIC 1520. The labeling of the time axis is unaffected by the earthquake time multiplier.

```
* * * * * * * * * * * * * * *

P R O G R A M   L Z A K -  C 6 4

* * * * * * * * * * * * * * *

DEVELOPED BY M. SAIIDI & R. LAWVER

AUGUST 1983


LIABILITY FOR THE USE OF THIS PROGRAM
IS THE RESPONSIBILITY OF THE USER.



PROJECT TITLE ?
SIX-STORY FRAME
UNITS ?
KIP INCH
DAMPING COEFFICIENT ?
0.26
EQUIVALENT & TOTAL MASS ?
0.974 , 1.242
GRAVITY ACCELERATION ?
386
EQUIVALENT HEIGHT ?
675
FACTOR TO NORMALIZE RESPONSE ?
1.22
YIELD & ULTIMATE MOMENTS ?
93600 , 250000
YIELD & ULTIMATE DISPLACEMENTS ?
3.35 , 16.73
EARTHQUAKE CODE ?
1
DURATION OF EARTHQUAKE (SEC)?
15
ACCELERATION & TIME MULTIPLIER ?
0.0395 , 1
TIME INTERVAL FOR NUMERICAL INTEGRATION?
0.02
RESPONSE PLOT REQUIRED ? Y=YES;N=NO
Y
ON PLOTTER OR PRINTER? 1-PRINTER; 2-PLOTTER
2

        (output)


MAXIMUM RESPONSE IN PLOT ?
30
RESPONSE AXIS LABEL ?
ROOF DISP. IN
```
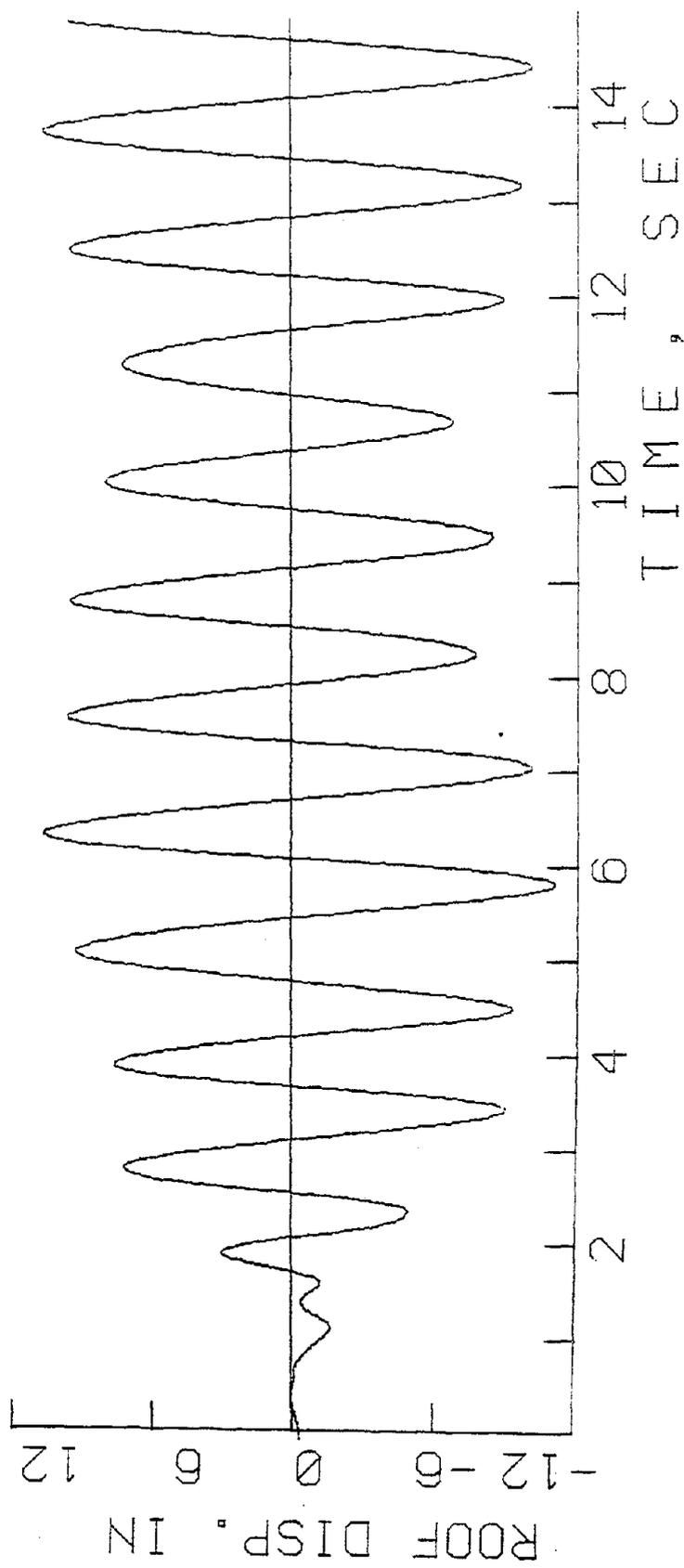
```
LZAK-C64                OUTPUT

PROJECT TITLE : SIX-STORY FRAME

UNITS : KIP INCH

DAMPING COEFFICIENT :  .26

EQUIVALENT MASS :  .974

TOTAL MASS :  1.242

EQUIVALENT HEIGHT :  675

FACTOR TO NORMALIZE RESPONSE :  1.22

YIELD MOMENT :  93600

ULTIMATE MOMENT :  250000

PRESS RETURN TO CONTINUE
YIELD DISPLACEMENT :  3.35

ULTIMATE DISPLACEMENT :  16.73

EARTHQUAKE RECORD :

     ELCENTRO 1940 NS

DURATION :  15  SECOND(S)

ACCLERATION MULTIPLIER :  .0395

TIME MULTIPLIER :  1

TIME INTERVAL FOR NUMERICAL INTEGRATION :  .02

RESPONSE PLOT REQUIRED




MAXIMUM DISPLACEMENT:        -11.146507
OVERTURNING MOMENT:          -161238.688
MAXIMUM SHEAR:               -238.872131
NUMBER OF ITERATIONS:         750


     WAIT FOR RESPONSE HISTORY
```

Fig. 1. - Response History for the Six-Story Frame.

```
* * * * * * * * * * * * * *

P R O G R A M   L Z A K -   C 6 4

* * * * * * * * * * * * * *

DEVELOPED BY M. SAIIDI & R. LAWVER

AUGUST 1983


LIABILITY FOR THE USE OF THIS PROGRAM
IS THE RESPONSIBILITY OF THE USER.



PROJECT TITLE ?
MF 1
UNITS ?
KN MM
DAMPING COEFFICIENT ?
0.8
EQUIVALENT & TOTAL MASS ?
0.00368 , 0.00465
GRAVITY ACCELERATION ?
9810
EQUIVALENT HEIGHT ?
1590
FACTOR TO NORMALIZE RESPONSE ?
1.2
YIELD & ULTIMATE MOMENTS ?
17900 , 18900
YIELD & ULTIMATE DISPLACEMENTS ?
6.84 , 10
EARTHQUAKE CODE ?
1
DURATION OF EARTHQUAKE (SEC)?
15
ACCELERATION & TIME MULTIPLIER ?
1.149 , 0.4
TIME INTERVAL FOR NUMERICAL INTEGRATION ?
0.02
RESPONSE PLOT REQUIRED ? Y=YES;N=NO
Y
ON PLOTTER OR PRONTER? 1-PRINTER; 2-PLOTTER
2


      (output)


MAXIMUM RESPONSE IN PLOT ?
 12
RESPONSE AXIS LABEL ?
ROOF DISP. MM
```

```
LZAK-C64                OUTPUT

PROJECT TITLE : MF1

UNITS : KN MM

DAMPING COEFFICIENT :  .8

EQUIVALENT MASS :  3.68E-03

TOTAL MASS :  4.65E-03

EQUIVALENT HEIGHT :  1590

FACTOR TO NORMALIZE RESPONSE :  1.2

YIELD MOMENT :  17900

ULTIMATE MOMENT :  18900

PRESS RETURN TO CONTINUE

YIELD DISPLACEMENT :  6.84

ULTIMATE DISPLACEMENT :  10

EARTHQUAKE RECORD :

     ELCENTRO 1940 NS

DURATION :  15  SECOND(S)

ACCLERATION MULTIPLIER :  1.149

TIME MULTIPLIER :  .4

TIME INTERVAL FOR NUMERICAL INTEGRATION : 8E-03

RESPONSE PLOT REQUIRED



MAXIMUM DISPLACEMENT:        29.2772894
OVERTURNING MOMENT:          23456.2472
MAXIMUM SHEAR:               14.7523567
NUMBER OF ITERATIONS:        750


     WAIT FOR RESPONSE HISTORY
```
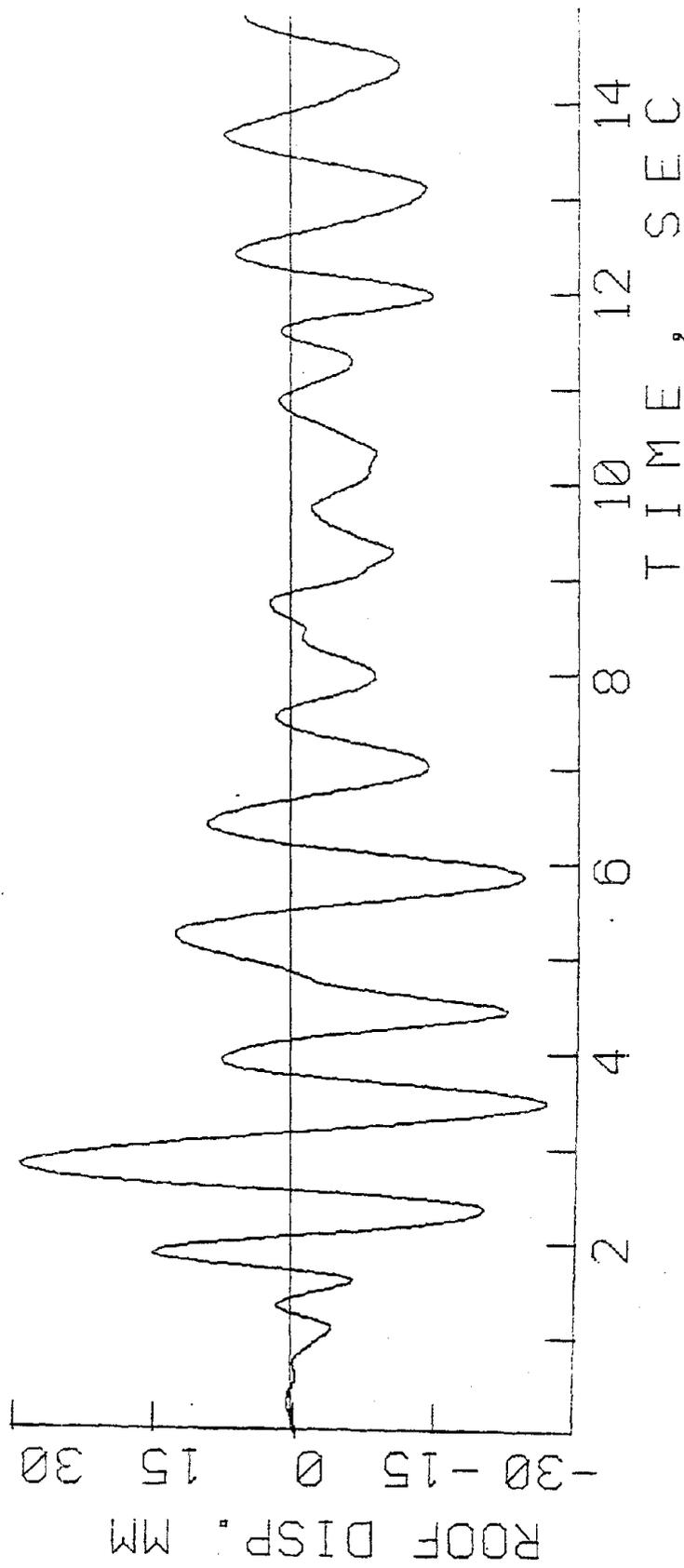
Fig. 2 - Response History for MF1.

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APPENDIX

Reprint

APPLICATION OF MICROCOMPUTERS IN EARTHQUAKE
DESIGN OF REINFORCED CONCRETE
BUILDINGS

by

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APPLICATION OF MICROCOMPUTERS IN EARTHQUAKE
DESIGN OF REINFORCED CONCRETE
BUILDINGS

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ABSTRACT

A simple nonlinear model for seismic response
history analysis of reinforced concrete plane frames
is outlined, and its implementation on a Commodore 64
is discussed. The method requires two nonlinear
models, one for static analysis of multistory frames
and the other for dynamic analysis of equivalent
"single-degree" systems. A BASIC computer program is
developed for each of these tasks. The program for
the dynamic analysis includes a data bank of five
earthquake records to facilitate the evaluation of
seismic vulnerability of a given design for a variety
of earthquakes.

A numerical example is presented to demonstrate
the application of the model. It is shown that the
method, which uses a state-of-the-art model, was suc-
cessfully implemented on a low-cost microcomputer.

INTRODUCTION

The substantial research which has been carried
out in the past twenty years in the area of earth-
quake engineering has led to a significant amount of
data on the actual behavior of structures. In the
field of reinforced concrete, extensive experimental
studies have been aimed at developing an in-depth
understanding of parameters influencing the seismic
response. Many analytical models have been developed
which incorporate measured data to arrive at a more
realistic modeling technique. A substantial number
of analytical and experimental studies have confirmed
that, under a severe earthquake, the changes in struc-
tural element stiffness caused by yielding of the
steel should be taken into account if a realistic
estimate of the seismic response is to be obtained.
Accordingly, many inelastic analytical models have
been introduced which account for the instantaneous
changes of element properties as the elements yield.
Typically, however, these models are very compli-
cated, making the models more of a research tool than
design tool. The size and complexity of the computer
programs associated with these models have restricted
their implementation to only large capacity com-
puters. Having realized the complexities of the in-
elastic modeling, some researchers have developed sim-
plified nonlinear models which have been found suc-
cessful in estimating the seismic response. Some of
these models are sufficiently simple and short to be
implemented on mini- and microcomputers.

Few of the recent analytical models have been
utilized by the practicing engineer, the main reasons
being the complexity of these models and the lack of
necessary computer facilities. Even the proposed simp-
lified models have not been used for purposes other
than research. With the wide availability of microcom-
puters, it is possible to implement some of the
simple models on microcomputers and make them access-
ible to the practicing engineer. This paper presents
the application of a nonlinear seismic analysis

technique on microcomputers. The model, called the
Q-Model, had been previously developed and tested for
a variety of structures and earthquakes. In the pres-
ent study, the model was simplified further and many
of the analytical methods known to structural engi-
neers were incorporated. The computer programs asso-
ciated with the model were developed on a Commodore
64 in BASIC language, with interactive input/output.
This paper presents a summary of the method and
discusses its implementation on the Commodore. A
numerical example is presented to demonstrate the
application of the model.

DESCRIPTION OF THE METHOD

It is known that the response of linear multi-
degree-of-freedom (MDOF) systems can be represented
by a generalized coordinate chosen at an arbitrary
location in the system (1,2). An identical method
(called the Q-Model) can be used for nonlinear sys-
tems with relatively uniform distribution of stiff-
ness and mass (3). Two key points are involved in
successful formulation of the generalized coordinate
method for nonlinear systems: (1) identification of a
deformed shape of the structure during the nonlinear
response and (2) realistic representation of stiff-
ness variation of the structure and its hysteretic
behavior. The Q-Model approach uses a static non-
linear analysis of the total structure to determine
the deformed shape, and it incorporates a simple
hysteresis model which is known to represent the
energy dissipation characteristics of reinforced con-
crete structures. An equivalent single-degree-of-free-
dom (SDOF) model is used to determine response his-
tories. The properties of the SDOF model are deter-
mined based on the results of the static analysis, as
described below.

Static Analysis

A nonlinear static analysis of the multistory
structure is carried out for horizontal loads applied
at floor level. The distribution of the loads is the
same as that used in the Uniform Building Code (UBC)
for structures with a fundamental period of 0.7 sec.
or less (4). The structure is treated as a plane
MDOF system with one horizontal degree-of-freedom as-
signed to each floor and one rotational degree-of-
freedom to each joint. Structural elements are as-
sumed to consist of line elements having an elastic
middle portion and, at each end, a nonlinear rota-
tional spring. Nonlinearity is assumed to be concen-
trated at ends because, under lateral loads, the
maximum moments occur at ends. It is assumed that the
moment-curvature relationship consists of two parts:
pre-yielding and post-yielding branches. The yield
moments are calculated using routine methods and a
positive post-yielding slope is assumed to account
for strain-hardening of steel. The loads are applied
in small increments to allow for monitoring the grad-
ual changes in stiffness of the structure. The output

from the nonlinear analysis consists of a backbone base moment vs. top-floor displacement curve. This curve is idealized by a bilinear relationship, using engineering judgement (Fig. 1). The floor displacements of the structure corresponding to the break point of the idealized curve are normalized by the roof displacement and are assumed to represent the displaced shape of the structure, (p). The weighted centroid of the displaced shape is chosen as the point for which the dynamic response is calculated (Fig. 2). If m_i = mass at floor i; h_i = height from the base at floor i; n = number of floors; and p_i = normalized displaced shape at floor i, the location of this point relative to the base (equivalent height) is computed from the following equation.

$$L_e = \sum_{i=1}^{n} m_i p_i h_i / \sum_{i=1}^{n} m_i p_i$$

Dynamic Analysis

The structure is assumed to be represented by an equivalent SDOF system consisting of a mass, mounted on a massless rigid bar (Fig. 3). The bar is hinged to the ground, and its rotation is controlled by a nonlinear rotional spring. To account for energy dissipation during small-amplitude responses, a viscous damper is included in the model.

The dynamic equilibrium equation is formulated as (3)

$$M_e \ddot{x} + C\dot{x} + Kx = -M_t \ddot{x}_g$$

in which

$$M_e = (\sum_{i=1}^{n} m_i p_i^2 / \sum_{i=1}^{n} m_i p_i) M_t ; \quad M_t = total$$

mass of the structure; C = damping coefficient; K = instantaneous stiffness; $\ddot{x}_g$ = ground acceleration; and x, $\dot{x}$, $\ddot{x}$ = relative displacement, velocity, and acceleration of the equivalent mass. This equation is formulated in an incremental form and integrated for small time intervals using Newmark's method assuming a constant acceleration over each time interval (5). The instantaneous stiffness is calculated using the rules of Q-hyst hysteresis model (3) which has been found to represent the behavior of reinforced concrete systems (Fig. 4). The model operates on the idealized curve explained in the previous section, with the abscissa modified by the value of p at L_e to arrive at displacement at the equivalent height.

The output from the dynamic analysis will include displacement time history at L_e which can be converted to displacement at any desired floor through multiplying the displacement by the ratio of p at that floor and p at L_e. The maximum base moment and base shear are also calculated. Having the maximum displacement, it is possible to estimate the maximum moments and ductility demands (maximum rotation/yield rotation) using the output from the static nonlinear analysis. Because of the approximations involved in computing the properties of the equivalent system, these quantities should be viewed as approximate values for moments and ductility demands.

IMPLEMENTATION ON COMMODORE 64

The Q-Model was programmed on a commodore 64 using BASIC. The commodore 64 is an 8-bit computer with 38911 bytes available to the user. Two separate programs were developed, one for static analysis and the other for dynamic analysis. Both of these programs are saved on a 5¼ inch floppy disk.

Static Analysis Program. The nonlinear static analysis procedure is implemented in a program named "NAFSHEL" standing for Nonlinear Analysis of Frames Subjected to Horizontal External Loads. The program is designed for plane rectangular frames. The input to the program is provided interactively, and consists of span lengths, story heights, moment-curvature relationships, and the loads.

To minimize the amount of required memory space, special attention is given to the storage of element and structural stiffness matrices. Because axial deformations are ignored for all structural elements, it is necessary to use vectors with a length of only three elements for beams and six elements for columns. Full advantage is taken from the fact that the structural stiffness matrix is symmetric and banded. A predetermined joint numbering is used to minimize the band width. The structural stiffness matrix is partitioned and static condensation is used to determine the lateral stiffness matrix.

For each load increment, element end forces are compared with yield moments and the element and structural stiffness matrices are updated as necessary. The lateral displacements, member end moments, and the ductilities are determined for each load increments and printed. All the necessary subroutines are incorporated in the same file and, hence, once the program is loaded, it is ready to be used without a need for any additional time to load and reload different subroutines.

Dynamic Analysis Program. The response history analysis of the equivalent SDOF system is implemented in program LZAK-C64. Similar to "NAFSHEL", the input to this program is prepared interactively. The input includes properties of the equivalent SDOF system, an index to identify the earthquake record, the number of seconds of the earthquake record to be used in the analysis, and other parameters such as scaling factor to control the intensity of the input ground acceleration and the time interval for numerical integration.

Currently, a data bank of five well-known earthquakes is incorporated in the program. The acceleration records are the first fifteen seconds of the following earthquakes:

El Centro 1940, NS
El Centro 1940, EW
Taft 1952, S69E
Bucharest 1977, NS
8244 Orion Blvd. 1971, NS

The stiffness of the system is determined based on the deformation history using a subroutine which implements the Q-hyst model. For each time interval, incremental displacements and base moments are found. The output includes a plot of displacement history, and the displacement, base shear and base moment maxima. Similar to NAFSHEL, the main program, the subroutines, and the earthquake data bank are integrated in a single file to minimize the reading time from the disk. It should be noted that for a given structural design, the static analysis needs to be carried out only once to determine the properties of the equivalent SDOF system. Then the dynamic response may be checked for different earthquakes, running program LZAK-C64 for as many times as necessary.

NUMERICAL EXAMPLE

A five-story two-bay reinforced concrete frame was used to demonstrate the application of the programs. The span lengths were 20 feet and story heights were 10 feet at second through fifth stories and 15 feet at the first story. The yield moments, yield curvatures, and the ratio of post-yielding slopes over cracked slopes are shown in Table 1. These values a.e based on the assumption that the frame is lightly reinforced and that "weak-girder" philosophy of design has been used. Floor weights were assumed to be 150 kip each, including the applicable portion of column weights.

To determine the properties of the equivalent system, the frame was analyzed using program NAFSHEL for lateral loads with a triangular distribution, applied in small increments. For each increment the lateral displacements, member end moments and member end ductilities were recorded. The resulting base moment vs. top-floor displacement is shown in Fig. 5. The curve was idealized as shown in the figure. Floor displacements corresponding to the break point were normalized with respect to the top floor (Table 2) to obtain the deformed shape of the frame. This shape and other information about the frame were used in the formulas presented in the previous section and the properties of the equivalent system were found (Table 2).

The equivalent SDOF system was analyzed for the first 15 seconds of the earthquake records stored in LZAK-C64 data bank. The peak acceleration in all cases was normalized to fifty percent of gravity acceleration. The displacement response histories are shown in Fig. 6, and the maximum roof displacement and base moments are listed in Table 3. Displacements at other floors can be obtained by multiplying the roof displacement by p at that floor. The displacement histories were obtained on a Commodore Graphic Printer using character graphics and then reduced. A printer/plotter is to be available in the near future, which is expected to produce better quality plots. The numerical integration time step for all the earthquakes was 0.02 sec. resulting in 750 iteration for each record. The time required for each dynamic analysis was approximately 11 minutes, with 6 minutes for computation and printing the output and 5 minutes for plotting the response history.

It can be seen in the response histories that the structure performed differently for various earthquakes.The peak roof displacement varied significantly from one earthquake to the other. Clearly, the peak value for the Bucharest record can not be accomodated by the frame. The waveforms reflect different number of high-amplitude cycles which is important in design. The change in the effective period can also be determined which can be interpreted as representative of reduction in the effective stiffness. Having displacement maxima at different floors, it is possible to determine relative story drifts and check against code limits.

The maximum ductility demands for different records are listed in Table 4. Elements are grouped based on the flexural type (each type has the same moment-curvature values). It can be seen that the ductility demand for the Bucharest record is beyond the ductility capacity of any ordinary reinforced concrete element. Among other earthquakes, the east-west component of El Centro led to the largest ductility demands, some of which may not be easily provided by ordinary reinforced concrete element. Assuming

that all the earthquake records used in the analysis are representative of the types of earthquakes likely to occur at the site during the lifetime of the frame, the designer of this frame could come to the conclusion that the frame may be too "flexible" and a redesign could result from this analysis.

DISCUSSION

The work leading to this paper demonstrated that it was possible to implement some of the state-of-the-art simple analytical models on inexpensive microcomputers, and make them accessible to design engineers. The programs, one for nonlinear static analysis of reinforced concrete plane frames and the other for nonlinear response history analysis of equivalent SDOF systems, were developed in the most straightforward fashion in that no auxilary memory or storage area was used for execution of the programs. While this is an advantage, it limits the size of the frame which can be analyzed (in the static program) and the size of earthquake data bank (in the dynamic program).

The success in implementing relatively sophisticated techniques on microcomputers should not overlook the necessity of basic understanding of the principles. Familiarity of the designer to theoretical background for these techniques is a key point in an overall successful utilization of advanced methods. Nevertheless, the "translation" of these advanced methods to what can be used on low-cost microcomputers is a very important step in providing the "tools" needed for wide-spread application of the methods.

ACKNOWLEDGMENT

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TABLE 1 - MOMENT-CURVATURE PROPERTIES

	Yield Moment (k-ft)	Yield Curvature (1/ft)	Slope Ratio
First-Story Columns	600	0.004	0.1
First-Floor Beams	200	0.005	0.1
Typical-Story Columns	400	0.003	0.1
Typical-Floor Beams	150	0.003	0.1

TABLE 2 - DISPLACED SHAPE AND EQUIVALENT SDOF SYSTEM PROPERTIES

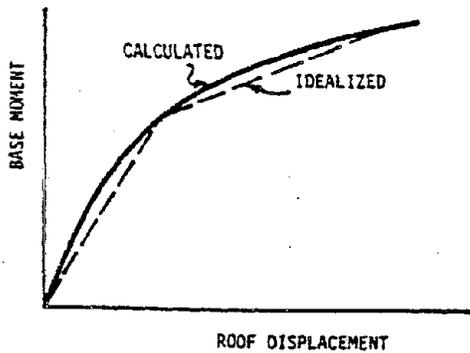| Displaced Shape	
Roof	1.
Fourth Floor	0.828
Third Floor	0.624
Second Floor	0.401
First Floor	0.193
Equivalent Mass (kip-mass)	17.4
Equivalent Height (ft)	41.7
Base Moment at Break Point (k-ft)	3570
Displacement at Break Point (ft)	0.821
Slope of Second Branch in Idealized Curve (k-ft/ft)	1790

TABLE 3 - MAXIMUM ROOF DISPLACEMENT AND BASE MOMENT

Earthquake	Maximum* Displacement (ft)	Maximum* Base Moment (k-ft)
El Centro NS 40	2.03	4,875
El Centro EW 40	4.02	7,602
Taft SE 52	1.47	4,115
Orion Blvd NS 71	1.35	3,943
Bucharest NS 77	10.14	15,957

*Quantities shown are absolute values

TABLE 4 - MAXIMUM DUCTILITY DEMANDS

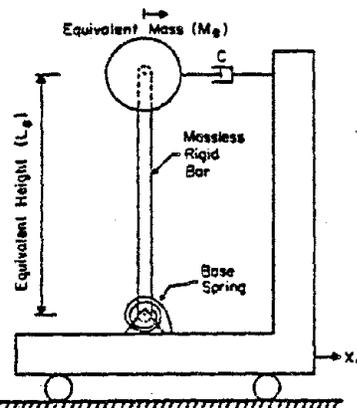| Earthquake	First Story Columns	First Floor Beams	Typical Story Columns	Typical Floor Beams
El Centro NS 40	6.1	2.1	3.6	2.6
El Centro EW 40	11.5	3.9	8.0	5.0
Taft SE 52	4.2	1.6	2.3	1.9
Orion NS 71	3.6	1.4	2.1	1.7
Bucharest NS 77	29.	9.8	21.	12.7
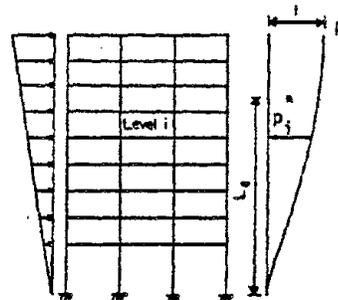
Fig. 2 - Static Loading and Displacement

Fig. 1 - Force-Deformation Curve for the Structure

Fig. 3 - The Equivalent SDOF System