DETERMINATION OF ACTION REDUCTION FACTORS FOR REINFORCED CONCRETE SHEAR WALL UNDER BLAST LOAD

By

Salisu Dahiru*, Abubakar Idris, and Mohammed Jibrin Kaura****
Department of Civil Engineering Technology, Nuhu Bamalli Polytechnic, Zaria
Department of Civil Engineering, Ahmadu Bello University, Zaria
Corresponding E-mail: salisudahiru@ymail.com

ABSTRACT
Ductility is of prime interest in blast resistant design, since it governs the degree in which overloads can be resisted by re-distribution of internal forces and the amount of energy dissipation capacity of structures, as a function of global ductility of structural system. Today, Engineers are facing the challenges of terrorist activities, that resulted in the destruction of several buildings and loss of hundred of thousands of lives. Reinforced concrete structures are generally brittle; there is therefore the need to have adequate knowledge on their capacity to dissipate energy under extreme events such as blast and earthquakes. In this paper, the energy dissipation factors "R" as functions of global ductility of reinforced concrete shear wall, were established based on various blast load scenario. The developed algorithm for the determination of the action reduction factors was implemented through a computer program written in FORTRAN 77. It was established in the research that, the charge weight of an explosive, has negligible effect on the blast resistant capacity of the wall that was particularly studied. The damage of the shear wall was influenced by standoff distance (distance between the point of detonation and the structure). The damage is higher, when the point of explosion is small. Accessibility to a building by terrorist is therefore a very important design criterion of blast resistant structures.

Keywords: Capacity Spectrum, Demand Spectrum, blast, Standoff distance, Charge weight.

INTRODUCTION

Research has been undertaken over the past half a century on the modeling of blast pressure on objects and structures [1, 2, 3, 4]. The recommended expressions for the blast generated maximum (peak) static over-pressure enable predictions to be made in the open field for any given stand-off distance and blast load expressed in terms of Trinitroluene (TNT) equivalence. The reflected over-pressure resulting from interaction of the blast wave with a stationary target surface has also been modeled [4].

In this study, reinforced concrete wall was subjected to linear elastic dynamic analyses based on pressure function (Equation 1) that was well established in the literature [5, 6, 7, 8, 9, 10]. The wall was treated as a single-degree-of freedom substitute structure in the analyses.

The computed response behaviour was presented in the form of acceleration and displacement histories along with response spectra. The response spectrum solution considered in this study was adopted [5].

$$P(t) = P_{max}\left(1 - \frac{T}{t_d}\right) \qquad (1)$$

where, P_{max} is the maximum blast pressure, T is the elastic period of the structure in seconds, t_d is the blast load duration in seconds. Equation (1) is a rectangular blast pressure-time function

RESPONSE SPECTRUM SOLUTION PROCEDURE

The procedure for the response spectrum solution presented in [5], comprises four key steps as summarized as follows:

Determination of Peak Acceleration (PA)

Step 1: Calculating scaled distance (Z) using the following equation:

$$Z = \frac{R}{W^{13}} \quad (2)$$

Where R is the scale distance in metres and W is the charge weight of the blast in kg based on TNT equivalence

Step 2: Calculating static over-pressure P_{so} from the following relations [1]:

$$P_{so} = \frac{6.7}{Z^3} + 1 \text{ bar } (P_{s0} > \text{bar})$$

$$P_{so} = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} - 0.019 \text{ bar } (0.1 \text{ bar} < P_{so} < 10 \text{ bar}) \quad (4)$$

Step 3: Calculate the maximum static over-pressure P_{max}:

$$P_{max} = 1.8P_{so} \quad (5)$$

Step 4: Calculate the coefficient of the reflected over-pressure C_r

$$C_r = 3(P_{smax})^{1/4} \quad (6)$$

Step 5: Calculating total over-pressure P_{Tmax}

$$P_{rmax} = C_r P_{Tmax} \quad (7)$$

Step 6: Calculating total blast load

$$W_{blast} = P_{Tmax} A \quad (8)$$

Where A is the frontal area of the structure.

Step 7: Calculating peak acceleration PA

$$PA = \frac{\text{Total blast load}}{\text{total mass}} \quad (9)$$

Determination of First Corner Period (T_1) and Maximum Response Velocity (RSV_{max})Step 8: Calculate the blast front velocity

$$U = a_o\sqrt{\frac{6P_{smax} + 7P_0}{7P_0}} \quad (10)$$

where a_o is the speed of sound (=3.35m/sec)

Step 9: calculating "clearing time

$$"T' = \frac{3S}{U} \quad (11)$$

Where S is the minimum dimension on the frontal surface of the blast.

Step 10: Calculating corner period ratio T_1/T' from the following equation

$$\frac{T_1}{T'} = 3.25 - 0.25(S-1) \quad (12)$$

Step 11: Calculating maximum response spectral velocity (RSV_{max}) using

$$RSV = PA \frac{T}{2\pi} \quad (\text{for } T \leq T_1)$$

$$RSV = PA \frac{T_1}{2\pi} \quad (\text{for } T > T_1) \quad (14)$$

Where T is the fundamental period of the structure

Determination of Displacement and Acceleration Demand at the "Performance Point"

Step 12: Obtaining demand curve for the Acceleration Displacement Response Spectrum (ADRS) diagram using the following equation

$$a = \frac{(RSV_{max})^2}{\Delta} \quad (15)$$

where Δ is the displacement at top of the shear wall.

Step 13: Obtaining capacity curve by push-over analysis. This was made available in a recent study [5] for the particular wall investigated in this study.

Step 14: Intercepting demand curve with capacity curve to identify performance point.

Determination of the Action Reduction (Ductility) Factor 'R'

Step 15: Calculate the effective elastic stiffness of the structure based on the FEMA drift limit of

1% for life safety limit states [11], using the following equation

$$K_{eff} = \frac{4\pi^2 m_{eff}}{T^2} \qquad (16)$$

Where m_{eff} is the effective mass of the structure

T is the fundamental period of the structure

Step 16: Calculate the structure stiffness at the performance point as follows

$$K_{per} = \frac{m_{eff}\, a}{\Delta} \qquad (17)$$

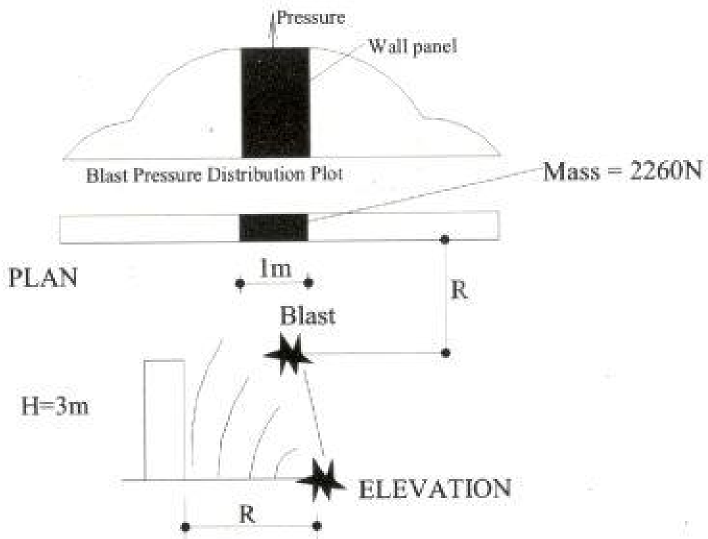
Step 17: As proposed in this study, the structure action reduction (Ductility) factors were established as follows:

$$R = \frac{K_{eff}}{k_{per}}$$

METHODOLOGY

In the assessment of the energy dissipation capacity of reinforced concrete structures under blast load, a reinforced concrete shear wall (Fig.1) that was studied in a separate recent investigation was considered [5]. The above procedure (equations 1 to 17) was implemented through a computer program written in FORTRAN 77. The weight of the structure and its effective natural (fundamental) period are 2260N and 0.05 seconds respectively.

The influence of stand off distance and the charge weight on the capacity of the shear wall to dissipate energy from the blast loading were investigated. The action reduction factor (ductility factors) is a measure of the energy dissipation capacity denoted by R. R = 1 is an indication of zero energy dissipation. A value of R above (eqn.18) is an indication of reserved ductility (energy dissipation capacity), and a value of R less than 1, is an indication of less than required capacity, which is an indicator of a system risk under blast load. The program listing was given in Appendix 1. The effective stiffness of the wall from equation 15 is equal to 35MN/m.



RESULTS AND DISCUSSION

A flexible computer program written in FORTAN 77, for the generation of the Acceleration Response Spectrum of Reinforced Concrete infill frames was presented in this paper. The program was used to analyse a Reinforced Concrete Shear wall. The Acceleration Response Spectrum (Demand Spectrum) was intercepted with the Capacity Spectrum obtained form the result of pushover analysis of the shear wall [5].

Figs. 2 to 6 show the plots of the demand and capacity spectrum for the reinforced concrete shear wall. The capacity spectrums were plotted from the results of push over analysis performed elsewhere [5]. In each case the two curves were intercepted, and the values of the spectral acceleration as well as the displacement (Δ) were recorded. Fig. 1 is for a wall subjected to a dynamite of charge weight 500kg of TNT equivalence at a stand off distance of 12m. In Fig. 3, the same charge weight was maintained, but the stand off distance was increased to 20m, in order to study the effect of the distance between explosive point and the structure. The effect of reduced charge weight on the blast effect was also studied. In Fig. 4 and Fig. 5, the charge weight of 100kg of TNT equivalence with stand off distance of 12m and 20m were respectively tested. Finally, a charge weight of 500kg and stand off distance of 6m were tested, as shown in Fig. 6.

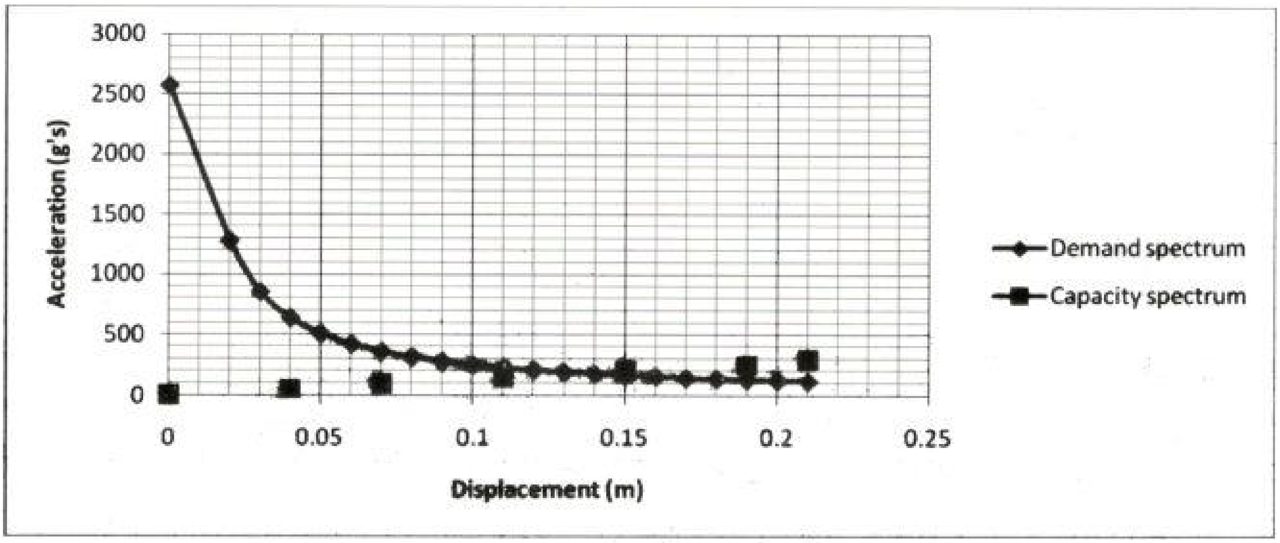


Fig 2 Acceleration Displacement Response Spectrum (ADRS) for W=500kg, R=12m

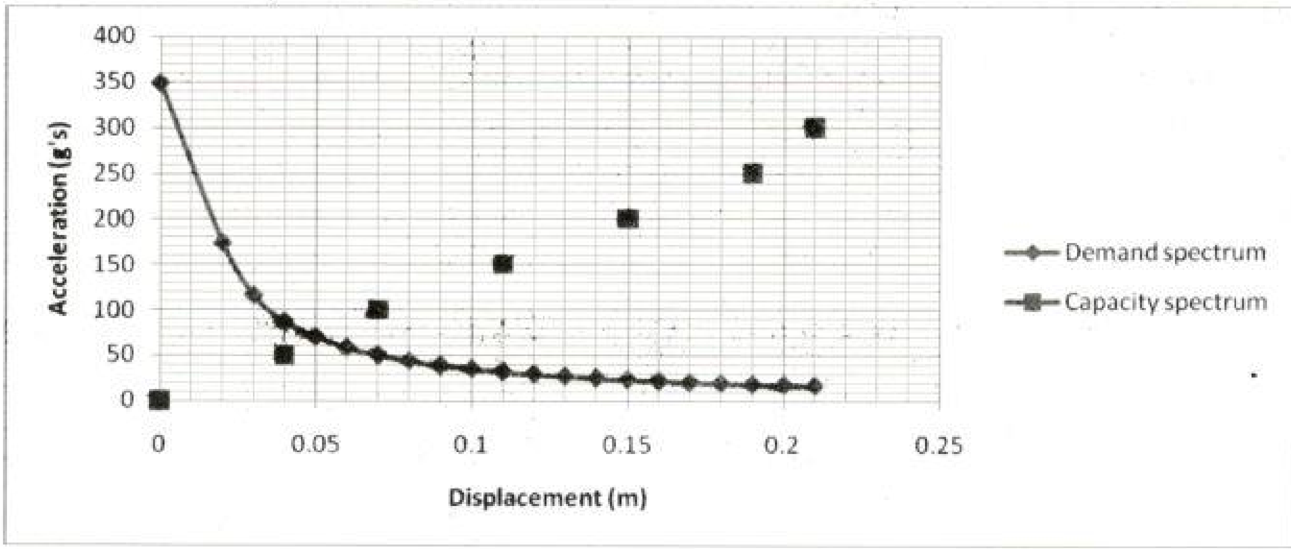


Fig. 3 Acceleration Displacement Response Spectrum (ADRS) for W=500kg, R=20m

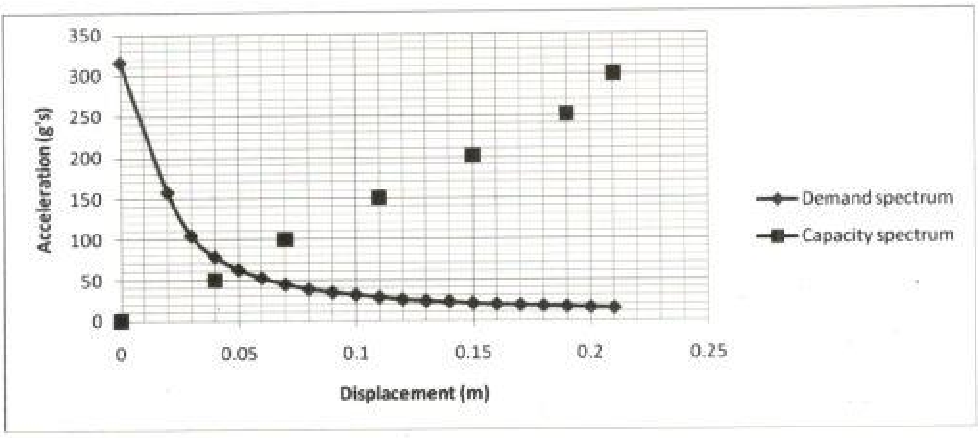


Fig. 4 Acceleration Displacement Response Spectrum (ADRS) for W=100kg, R=12m

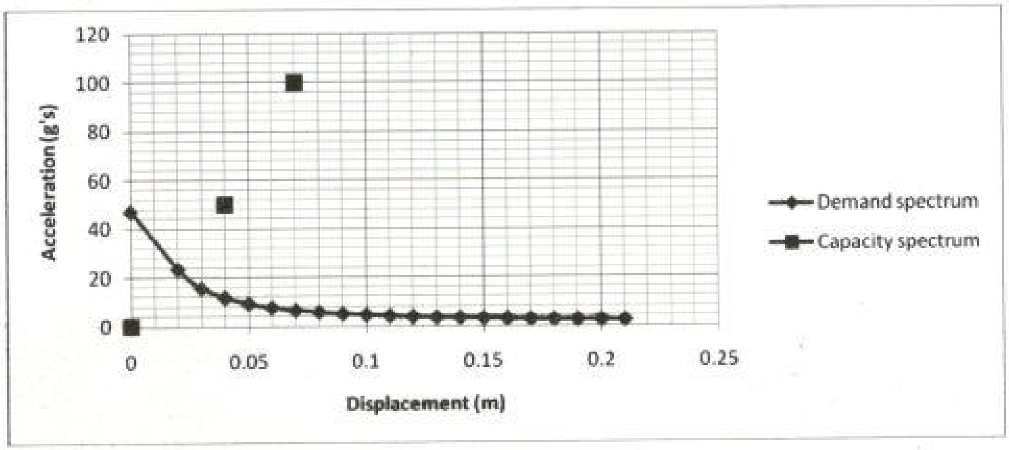


Fig. 5 Acceleration Displacement Response Spectrum (ADRS) for W=100kg, R=20m

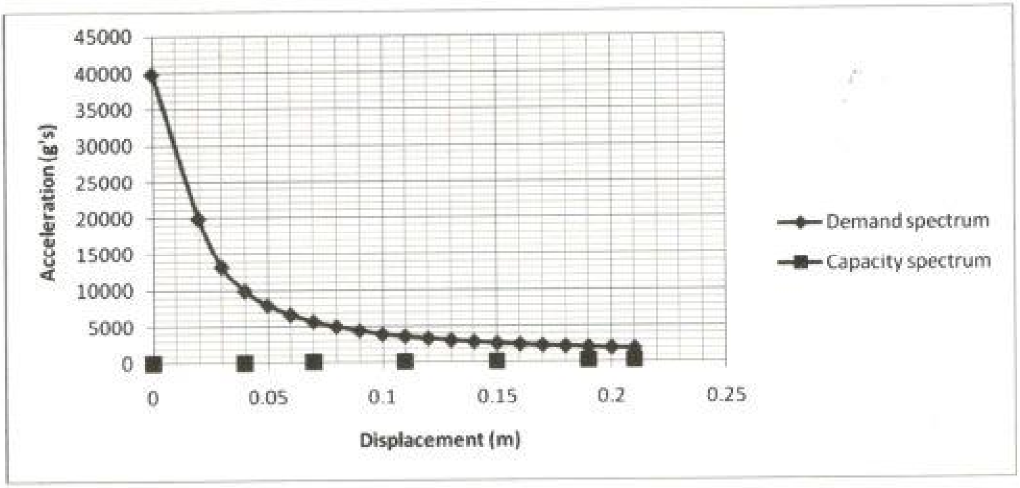


Fig. 6 Acceleration Displacement Response Spectrum (ADRS) for W=500kg, R=6m

The generated stiffnessess and the inherent ductility of the reinforced concrete shear walls are presented in Table 1. At stand off distance of 12m, the wall ductility (ratio of the effective wall stiffness and the stiffness at the performance from the ADRS) at both 500kg and 100kg charge weight is 1.2. Similarly, when the stand off distance increased to 20m, the inherent ductility is 1.3 for both 500kg and 100kg charge weight. This is an indication that, the charge weight has negligible effect on the capacity of the wall to dissipate energy through ductile behavior. The factor that mostly influenced damage is the standoff distance (distance between the point of detonation and the structure).

Based on the findings in this study, the following recommendations were made.

Important Reinforced Concrete facilities should be constructed with massive shear wall, as this results in high wall stiffness, and therefore contribute to the overall capacity of the facility to resist damage under blast loading.

Large standoff distance should be maintained, by increasing the access distance of the potential terrorists. This is because, the closer the distance between structures and the point of explosive detonation, the higher the damage.

CONCLUSION

A flexible computer program written in FORTAN 77, for the generation of the Acceleration Response Spectrum of Reinforced Concrete infill frames was presented in this paper. The program was used to analyze a Reinforced Concrete Shear wall. It was established that the charge weight of an explosive has negligible effect on the blast resistant capacity of the wall. The damage of the shear wall was influenced by standoff distance (distance between the point of detonation and the structure). The damage is higher, when the point of explosion is small. Accessibility to a building by terrorist is therefore a very important design criterion of blast resistant structures.

REFERENCES

(1) Brode, H.L. *Seismic Evaluation and Retrofit of Concrete Buildings*, Vol. 1 and 2, Redwood City CA: Applied Technology Council, 1996.

(2) Henrych, J. *The Dynamics of Explosions and its Use,* Elsevier Science Publisher, 1979

(3) Kingery, C.N. and Bulmash, G. *Airblast parameters from TNT Spherical Air Blast and Hemispherical Surface Blast*, Technical Report ARBRL-TR-03555, US Armament, 1984

(4) Smith, P. D. And Hetherington, J. G. *Blast and Ballistic Loading on Structures*, 1st edition, Butterworth-Heinemann, Oxford, United Kingdom, 1994

(5) Nelson, L. Priyan, M, Tuan, N. *Response Spectrum Solution for Blast Loading*, Electronic Journal of structural Engineering EJSE Vol. 4. 2004, pp 28-44

(6) Remennikok, A. M. *A Review of Methods for Predicting Bomb Blast Effects on Buildings*, Journal of Battlefield technology Vol. 6, No. 3, 2003, pp 5-10.

(7) Mendis, P. Gupta, A, Ngo, T, Ramsy, J. *Blast Loading and Blast Effects on Structures -- An Overview*, Electronic Journal Structural Engineering, Vol. 7 (Special Issue 1): Loading on Structures, 2007, pp 76-91.

(8) Luccioni, B. M., Ambrosini, R. D., Danesi, R. F. *Analysis of Building Collapse under Blast Loads*, Engineering structures, Vol. 26, 2004, 63-71.

(9) Asteris, P. G. *Finite Element Micro Modeling of In-filled Frames*, Electronic Journal Structural Engineering, Vol. 8, 2008, pp. 1-11

(10) Daneshjo, F and Gharighoran, A. *Experimental and Theoretical Dynamic System Identification of Damaged RC Beams*, Electronic Journal Structural Engineering, Electronic Journal Structural Engineering, Vol. 8, 2008, pp 29-39.

(11) Folz, B. and Filiatrault, A. *Performance-Based Seismic Design of Wood Framed Buildings*, Journal of Structural Division. American Society of Civil Engineers, Vol. 128, 2002, pp 39-47

APPENDIX 1: PROGRAM LISTING

```
      PROGRAM BLAST2010
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION XT(21),XDIS(21),ARES(21),XCAP(21),XDI(21)
      DIMENSION XBEL(21),XPT(21)
C     TIME IN SECONDS
      XTS=0.02
      XT(1)=0.01
      XT(2)=0.015
      XT(3)=0.02
      XT(4)=0.025
      XT(5)=0.03
      XT(6)=0.035
      XT(7)=0.04
      XT(8)=0.045
      XT(9)=0.05
      XT(10)=0.055
      XT(11)=0.06
      XT(12)=0.065
      XT(13)=0.07
      XT(14)=0.075
      XT(15)=0.08
      XT(16)=0.085
      XT(17)=0.09
      XT(18)=0.095
      XT(19)=0.105
      XT(20)=0.11
      XT(21)=0.115
C DISPLACEMENT IN MM
```

```
XDIS(1)=0.01
   XDIS(2)=0.02
   XDIS(3)=0.03
   XDIS(4)=0.04
   XDIS(5)=0.05
   XDIS(6)=0.06
   XDIS(7)=0.07
   XDIS(8)=0.08
   XDIS(9)=0.09
   XDIS(10)=0.10
   XDIS(11)=0.11
   XDIS(12)=0.12
   XDIS(13)=0.13
   XDIS(14)=0.14
   XDIS(15)=0.15
   XDIS(16)=0.16
   XDIS(17)=0.17
   XDIS(18)=0.18
   XDIS(19)=0.19
   XDIS(20)=0.20
   XDIS(21)=0.21
   XDI(1)=0.0
   XDI(2)=500.0
   XDI(3)=1000.0
   XDI(4)=1500.0
   XDI(5)=2000.0
   XDI(6)=2500.0
   XDI(7)=3000.0
   XDI(8)=3500.0
   XDI(9)=4000.0
   XDI(10)=4500.0
   XDI(11)=5000.0
   XDI(12)=5500.0
   XDI(13)=6000.0
   XDI(14)=6500.0
   XDI(15)=7000.0
   XDI(16)=7500.0
   XDI(17)=8000.0
   XDI(18)=8500.0
   XDI(19)=9000.0
   XDI(20)=9500.0
   XDI(21)=10000.0

OPEN(10,FILE='BLAST1.RES',STATUS='OLD',ER
R=20)
   GOTO 30
2                                          0
OPEN(10,FILE='BLAST1.RES',STATUS='NEW')
30  WT=2260.0
   WRITE(*,*)' INPUT STAND OFF DISTANCE
IN METERES'
   WRITE(*,*)'   '
   READ(*,*)XR
   WRITE(*,*)' INPUT CHARGE WEIGHT IN kg'
   WRITE(*,*)'   '
   READ(*,*)XXWT
   XWT=XXWT
C NOW COMPUTE THE SCALED DISTANCE XZ
   XZ=XR/(XWT**0.33333)
   XCB=(XZ**2)-(3.7*XZ)+4.2
   XPMAX1=(6.7/(XZ**3))+1.0
   IF(XPMAX1.GE.10.0)THEN
   GOTO 2000
   ELSEIF(XPMAX1.LT.10.0)THEN
   GOTO 3000
   ENDIF
2000 XPMAX2=XPMAX1
   GOTO 4000
3 0 0 0             X P M A X 2         =
(0.975/XZ)+(1.455/(XZ**2))+(5.85/(XZ**3))-0.019
   GOTO 4000
4000 XPMAX=XPMAX2*100.0
C NOW COMPUTE THE MAXIMUM
OVERPRESSURE XPEL
   XPEL=1.8*XPMAX
   DO 1230 I=1,21
   XBEL(I)=EXP(((-XCB)*XT(I))/XTS)
   XPT(I)=XPEL*((1.0)-(XT(I)/XTS))*XBEL(I)
1230 CONTINUE
C NOW COMPUTE THE COEFFICIENT OF
REFLECTED OVERPRESSURE CR
   CR=3.0*((XPEL/100.0)**(0.25))
C NOW COMPUTE THE TOTAL OVERPRESSURE
   XPTOTAL=XPEL*CR
C NOW COMPUTE THE TOTAL BLAST LOAD
   BLTOTAL=XPTOTAL*1.0*3.0
C NOW COMPUTE THE PEAK ACCELERATION
PA
   ACCELP=(BLTOTAL/WT)*1000.0
   WRITE(10,9015)ACCELP
9015   FORMAT(////,5X,'PEAK ACCELERATION
=',F20.2)
C NOW COMPUTE THE FRONT VELOCITY
C SPEED OF SOUND=335
   XSOUND=335.0
                                  X U     =
((((6.0*(XPEL/100.0))+7.0)/7.0)**0.5)*XSOUND
C NOW COMPUTE THE CLEARING TIME
XTCLEAR
C ACCORDIND TO THE UNIFIED FACILITY
CRITERIA (UFC)
   XTCLEAR=(3.0*3.0)/XU
C NOW COMPUTE CORNER PERIOD XTCORNER
      XTCORNER = XTCLEAR*(3.25-(0.25*(3.0-
1.0)))
C NOW COMPUTE MAXIMUM RESPONSE
VELOCITY XRV
   XRV=ACCELP*(XTCORNER/(2.0*3.142))
C DEMAN ACCELERATION RESPONCE
SPECTRUM PLOT
   DO 9000 I=1,21
   ARES(I)=(XRV**2)/XDIS(I)
```

```
9000 CONTINUE
    WRITE(10,9030)
9030 FORMAT(/,5X,70('*'))
    WRITE(10,9031)
9031 FORMAT(/,5X,'DYNAMIC RESPONSE OF
REINFORCED CONCRETE',/,
   +5X,'FRAME UNDER BLAST LOADING',/,
   +5X,'BY Engr SALISU DAHIRU')
    WRITE(10,320)
320 FORMAT(/,5X,70('*'))
    WRITE(10,410)WT
410 FORMAT(/,
   +5X,'BUIDING MASS      =',F12.2)
    WRITE(10,330)XR,XWT,XZ
330 FORMAT(/,
         +5X,'STAND UP DISTANCE IN m
=',5X,F10.5,/,
         +5X,'CHARGE WEIGTH IN kg TNT
=',5X,F10.5,/,
   +5X,'SCALED                    DISTANCE
=',5X,F10.5)
    WRITE(10,6332)
6332 FORMAT(/,'DEMAND SPECTRUM')
    WRITE(10,9001)(XDIS(I),ARES(I),I=1,21)
9001 FORMAT(/,5X,2F20.5)
    XPER = 0.05
    DO 7009 I = 1,21
    XCAP(I) = (0.20*(XDI(I)))/2700.0
7009 CONTINUE
    WRITE(10,6331)
6331 FORMAT(/,'CAPACITY SPECTRUM')
    WRITE(10,7008)(XDI(I),XCAP(I),I=1,21)
7008 FORMAT(/,5X,2F20.5)
    WRITE(10,1231)XPER,XTS
1231 FORMAT(/,5X,'FUNDAMENTAL PERIOD
(S)',F20.5,/,
   +5X,'BLAST LOAD DURATION (S)',F20.5)
    WRITE(10,1232)(XT(I),XPT(I),I=1,21)
1232 FORMAT(/,5X,2F20.5)
    STOP
    END
```