RESPONSE

TO

NRC REQUEST FOR

ADDITIONAL INFORMATION

MASONRY WALL RE-EVALUATION

(NRC IE BULLETIN 80-11)

FLORIDA POWER & LIGHT COMPANY

TURKEY POINT PLANT UNITS NO. 3 & 4

BECHTEL POWER CORPORATION

GAITHERSBURG, MARYLAND

MAY, 1982

[illegible]

QUESTION

1. Indicate whether the construction practice for the masonry structures at Turkey Point Plant Units 3 and 4 was in conformance with the provisions specified for the special inspection category in ACI 531-79. If not, explain and justify the use of allowable stresses.

RESPONSE

The use of allowable stresses per the ACI 531-79 special inspection category is valid for the following reasons:

(a) Masonry walls were constructed by personnel working from project drawings and specifications. These documents delineate requirements for handling, storage, preparation of materials, and erection (several of these requirements are outlined in the Turkey Point Units 3 & 4 Final Report in Response to IE Bulletin 80-11). These requirements were included to ensure the use of proper materials and workmanship and to prevent voids or other weaknesses. The quality control inherent in nuclear power plant construction provides assurance of good workmanship.

(b) Field Engineers (responsible for monitoring the progress of work and reporting any errors or inadequacies in materials or workmanship) were on the site during the construction of the masonry walls.

(c) The masonry wall walkdown procedure for Turkey Point required the recording of observations of wall conditions (cracks, condition of mortar joints, etc.). The walls were generally reported to be in good condition.

QUESTION

2. With reference to Section II of Reference 5, justify the proposed 67% increase in allowable stresses for masonry in tension and shear. For factored loads, the SEB criteria suggest the following factors:

Shear reinforcement and/or bolts	1.5
Masonry tension parallel to bed joint	1.5
Shear carried by masonry	1.3
Masonry tension perpendicular to bed joint	
for reinforced masonry	0
for unreinforced masonry	1.3

Reference:

(5) R. E. Uhrig letter to J. P. O'Reilly, NRC, dated April 3, 1981 (L-81-153)

RESPONSE

The 67% increase in allowable stresses for masonry shear and tension for factored loads was chosen in March, 1981, prior to the issuance of

the SEB criteria which was published in July, 1981. Code allowable stresses for shear and tension were increased by 67% for load combinations involving abnormal and/or extreme environmental conditions which are credible but highly improbable. Since the code allowable stresses (ACI 531-79, Chapter 10.1 of the commentary) are generally associated with a safety factor of 3, the 1.67 increase provides a factor of safety against failure of 1.8 (3 ÷ 1.67). In light of the nature of the loads considered here, a factor of safety of 1.8 is conservative and allows sufficient margin for abnormal and/or extreme conditions.

QUESTION

3. With reference to Page 10 of Reference 5, explain how modes higher than the fundamental mode were accounted for. Provide a sample calculation.

Reference:

(5) R. E. Uhrig letter to J. P. O'Reilly, NRC, dated April 3, 1981 (L-81-153)

RESPONSE

A FORTRAN computer code was developed to analyze masonry walls for axial load and flexural effects due to external and/or seismic loading. The modal analysis technique is used in conjunction with

the response spectrum method to obtain the seismic response of the wall model. The responses of the first three modes of the beam model are combined by the SRSS method to obtain the total response. The results of the computer code developed were verified against a nine mode solution. In lieu of a sample calculation (which would show only the input and output of the computer code), Attachment 1 is enclosed to provide a description and flow chart of the referenced FORTRAN computer code.

When the energy balance technique was used, the total required strain energy was calculated from the loads and deflections determined by the computer code referenced above. As already noted, this program considers the first three modes of the beam model.

When the arching method was used, the seismic inertial loading was obtained from the seismic acceleration corresponding to the natural frequency of the wall. The natural frequency and, by extension, the seismic loading were conservatively determined from an upper bound value of the wall deflection.

QUESTION

4. Explain how the openings and attachments from piping or equipment are accounted for in the beam analysis.

RESPONSE

(a) Openings

Block wall masses above openings and/or penetrations are equally distributed to the strips adjacent to the opening on both sides as additional mass for the purpose of analysis.

(b) Loads due to piping and/or attachments:

(i) The concentrated loads due to piping and/or attachments were considered as additional masses when elastic analysis and/or energy balance techniques were applied.

(ii) When the arching theory was applied, an equivalent distributed load q_E was substituted for the concentrated load and was added to the seismic inertial load. The equivalent distributed load was defined as

$$q_E = \frac{8 M_E}{L^2}$$

where M_E = maximum bending moment due to all external loads

L = wall span

This method was used only if M_E were located in the middle third of the span, or if M_E were not greater than 20% of the maximum seismic moment based on elastic considerations. Where the concentrated load did not meet either of the above requirements, the arching theory was not considered applicable.

QUESTION

5. Indicate how earthquake forces in three directions were considered in the analysis.

RESPONSE

In accordance with FSAR criteria, seismic forces were considered acting simultaneously in the vertical and in any horizontal direction. In-plane stresses due to seismic loads were generally insignificant; for two load-bearing walls which were analyzed by elastic methods, the out-of-plane horizontal loads were determined to be the governing horizontal loads. Therefore, seismic load due to the horizontal earthquake component in the out-of-plane direction was combined with the vertical seismic load using the absolute sum method in the consideration of seismic loads for the masonry wall evaluation.

QUESTION

6. In Reference 5, the Licensee indicates that the energy balance technique and arching theory have been used to qualify some masonry walls. The NRC, at present, does not accept the application of these techniques to masonry walls in nuclear power plants in the absence of conclusive evidence to justify this application. The Licensee is requested to indicate the number of walls which have been analyzed by each of these techniques.

Reference:

(5) R. E. Uhrig letter to J. P. O'Reilly, NRC, dated April 3, 1981 (L-81-153)

RESPONSE

A total of 55 masonry walls were qualified using arching theory; 24 walls were qualified using energy balance technique.

QUESTION

1. Energy Balance Technique

- For the walls which were analyzed by using the energy balance technique, provide technical basis to ensure that the ductile mode of failure will take place (if they fail).

- o Provide justification and test data (if available) to validate the applicability of the energy balance technique to the masonry structures at Turkey Point Units 3 and 4 with particular emphasis on the following areas:

  a. nature of the load

  b. boundary conditions

  c. material strengths

  d. size of test walls

RESPONSE

Energy Balance Technique

- o The energy balance technique is used to analyze masonry walls subjected to out-of-plane loads. For this particular loading condition a reinforced concrete block wall is a ductile structure, provided a flexural type of failure occurs with tensile yielding of the steel (Ref. 1). Flexural failure by yielding of steel is ensured by checking the compressive stress in the block to determine that its crushing strength is not exceeded. Experimental work performed by Sheppard (Ref. 2) indicates "considerable ductility" in concrete block walls having reinforcement ratios of 0.15% or greater. All walls analyzed by energy balance at Turkey Point meet this criteria.

o a) The energy balance technique was developed to analyze ductile structures subjected to seismic loads (Ref. 3). At Turkey Point energy balance is used primarily to determine the ability of reinforced masonry walls to resist earthquake loadings.

b) c) d) Boundary conditions, material strengths and wall size are all conditions that quantitatively affect the response of a particular wall. In order to apply the energy balance technique, the wall need only be shown to qualitatively respond in a ductile manner. It is the inelastic energy absorption associated with a ductile response which is the foundation of this method of analysis.

Actual physical evidence in support of the energy balance technique is cited in Reference 4. This reference investigates the ductile failure of catalytic cracking towers affected by the 1952 Arvin-Tehachapi earthquake. The study shows "general agreement between observed and computed values" of displacement.

References:

1) Scrivener, J. C., "Reinforced Masonry - Seismic Behavior and Design," Bulletin of New Zealand Society for Earthquake Engineering, Vol. 5, No. 4, December, 1972.

2) Sheppard, P., _et_. _al_. "The Influence of Horizontally-Placed Reinforcement on the Shear Strength and Ductility of Masonry Walls," 6th World Conference on Earthquake Engineering, New Delhi, India, 1977.

3) Blume, J. A., Newmark, N. M., Corning, L. H., "Design of Multistory Reinforced Concrete Buildings for Earthquake Motions," Portland Cement Association, Ill., 1961.

4) Housner, G. W., "Limit Design of Structures to Resist Earthquakes", World Conference on Earthquake Engineering, Berkeley, California, 1956.

QUESTION

2. Arching Theory

- Explain how the arching theory handles cyclic loading, especially when the load is reversed.

- Provide justification and test data (if available) to validate the applicability of the arching theory to the masonry structures at Turkey Point Plant Units 3 and 4 with particular emphasis on the following areas:

  a. nature of the load
  b. boundary conditions
  c. material strength
  d. size of the test walls

- If hinges are formed in the walls, the capability of the structures to resist in-plane shear force would be diminished, and shear failure might take place. This in-plane shear force would also reduce the out-of-plane stiffness. Explain how the effect of this phenomenon can be accurately determined.

RESPONSES

2. Arching Theory

- o The arching theory of confined masonry walls is based on an extensive full scale test program sponsored by the Defense Civil Preparedness Agency and the Veterans Administration (Ref. 1). The tests were performed in a "shock tunnel" in which a wall was "struck by a blast wave, the wave reflected from the wall returned to its source area, then re-reflected to strike the wall again, about 0.3 sec after the first loading. Thus, these tests provided information on the ability of [arching] walls to withstand a number of reversing loading cycles."

- o a) At the Turkey Point Plant, arching theory was used primarily to determine the ability of masonry walls to resist uniform pressure loadings and earthquake loadings. The test data of Reference 1 provides justification for applying arching theory to masonry walls subjected to pressure loads. Reference 1 also cites field evidence which confirms the increased resistance to out-of-plane earthquake loads of confined [arching] masonry walls over non-arching walls.

  b) Boundary conditions required for the application of arching theory were validated by walkdown inspection of the block walls to be analyzed.

c) Experiments on arching have been performed on walls that range in crushing strength from 1000 psi to 3000 psi (Ref. 2). The masonry walls at Turkey Point fall within this range.

d) The tests of Reference 2 were performed on walls arching over an 8'-0" span while those of Reference 1 spanned 8'-6". We consider that application of arching theory to the range of wall sizes encountered at Turkey Point is appropriate.

o At its present stage of development, arching theory cannot adequately account for the effect of hinge formation on in-plane shear capacity. However, the walls at Turkey Point analyzed by the arching method are not designed to act as shear walls or as bearing walls, and therefore are not subjected to significant in-plane load. This eliminates the need to determine how in-plane and out-of-plane loads interact.

References

1) Gabrielsen, B. L., Kaplan, K. "Arching in Masonry Walls Subjected to Out-of-Plane Forces," Earthquake Resistance of Masonry Construction, National Workshop, NBS 106, 1976.

2) McKee, K. E., Sevin, E., "Design of Masonry Walls for Blast Loading," ASCE Structural Journal, January, 1958.

DESCRIPTION OF FORTRAN COMPUTER CODE

1. INTRODUCTION

A fortran computer code "Block Walls" has been developed to analyze block walls for axial load and flexural effects due to external and/or seismic loading. The block wall is analyzed as a simplified three degree of freedom beam model. The modal analysis technique is used in conjunction with the response spectrum method to obtain the seismic response of the wall model. An iterative method is used to determine the actual stress and section properties (effective moment of inertia) of a wall section. Convergence criteria is established to verify that the assumed section condition results in the same inertial loading for two seccessive iterations.

The working stress method for concrete analysis is used for stress calculations. Finally, the calculated stresses are checked against the established allowables.

1.1 Determination of Section State (Cracked vs. Uncracked)

Iteration Procedure

1. For the first iteration, the wall is assumed uncracked.

2. As a result of Step 1, and based on the calculated inertial forces, the section is checked for cracking.

3. If cracked conditions exist, an effective moment of inertia is determined using the following ACI Formula:

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_t + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr}$$

$$M_{cr} = f_r \left(\frac{I_t}{y}\right)$$

where,

M_{cr} = Uncracked moment capacity.

M_a = Applied maximum moment on the wall.

I_t = Moment of inertia of transformed uncracked section.

I_{cr} = Moment of inertia of the cracked section.

f_r = Modulus of rupure.

y = Distance of neutral plane from tension face.

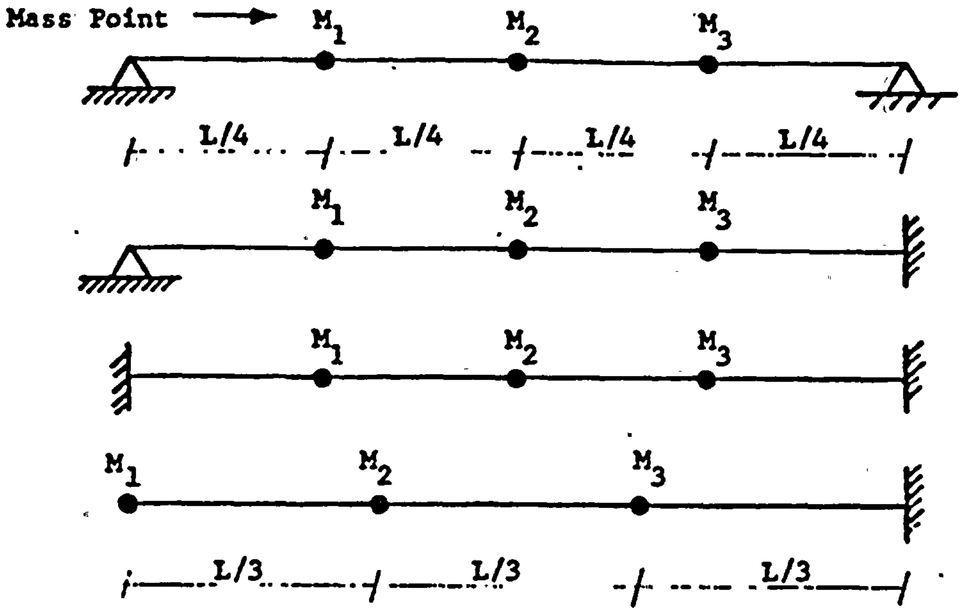
4. A new iteration is initiated to recompute the frequencies, mode shapes and modal participation factors.

5. The procedure is repeated until convergence is achieved.

1.2 Seismic Analysis

The wall is represented by a three degree of freedom simplified beam model. A response spectrum analysis is performed yielding the inertial loading to be imposed on the system.

Four types of end conditions are allowed for the beam model used to perform the analysis as shown schematically below:



1.3 Stress and Deflection Calculations

The stress calculations are performed for the final configration of the section using working stress methods. Based on inertial loads, applied external loads, and the computed section stiffness, the beam model deflection is determined.

1.4 Governing Codes

1. ACI 531-79 and commentary.

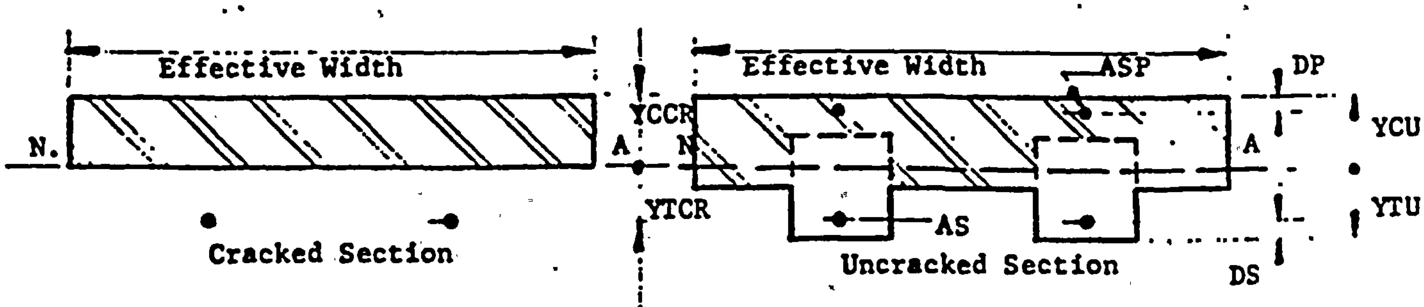
2. Uniform Building Code, 1970 edition.

3. Other codes as specified.

2. ANALYTICAL PROCEDURE

2.1 Block Wall Stress Calculation

The governing equations for block wall stress calculations are developed using a working stress approach.



Idealized Section for Analysis

The section properties are calculated based on a transformed section with the block material as a base. Using the standard concrete analysis equilibrium concept namely:

$\sum$FORCES = 0 or Tension = Compression
$\sum$Moment = M = Section Internal Moment

The following equations for stress calculation for bending are obtained:

<u>Case A</u> : Uncracked section

fMB = (M/IUCR) x YCU
fST = NSM x (M/IUCR) x (YTU-DS)
fSC = NSM x (M/IUCR) x (YCU-DP)

<u>Case B</u>: Cracked section

fMB = (M/ICR) x YCCR
fST = NSM x (M/ICR) x (YTCR-DS)
fSC = NSM x (M/ICR) x (YCCR-DP)

Note 1. For both Case A and Case B the axial compression stresses are calculated and interaction is checked.

$(fMA/FMA) + (fMB/FMB) \leq 1.0$

2. For axial tension it is assumed that the reinforcing steel only carries the tension.

Definition of variables used in the above equations:

M = Bending moment
FMB = Allowable masonry compressive stress due to bending
FMA = Allowable masonry compressive stress due to axial force
fMB = Masonry compressive stress due to bending
fMA = Masonry compressive stress due to axial force
IUCR = Uncracked moment of inertia
ICR = Cracked moment of inertia
YCU = Distance to extreme fiber in compression (uncracked)
YTU = Distance to extreme fiber in tension (uncracked)
YCCR = Distance to extreme fiber in compression (cracked)
YTCR = Distance to extreme fiber in tension (cracked)
AC = Transformed compressive area of section
NSM = Modular ratio for steel

2.2 Eigen Value Solution and Response Calculation

The following two matrices are determined based upon boundary conditions and structural properties.

Flexibility matrix = [F]
Mass Matrix = $\lceil M \rfloor$

1) Calculate transformation matrix $\lceil M^* \rfloor = \lceil M \rfloor^{-1/2}$

2) Using Gauss elimination technique with column pivoting, calculate the structural stiffness matrix.

$$[k] = [F^{-1}]$$

3) Calculate transformed stiffness matrix $[\bar{k}]$ such that:

$$[\bar{k}] = [\diagdown M^{*} \diagdown] \; [k] \; [\diagdown M^{*} \diagdown]^T$$

4) Tridiagonalize $[\bar{k}]$ using Householder's method and evaluate the characteristic value equation:

$$[\bar{k}] \; (\phi_i) + W^2{}_i \; (\phi_i) = 0$$

5) Calculate eigenvalues using Sturm sequence on the tridiagonal matrix.

6) Calculate eigenvectors using Wilkinson's method on the tridiagonal matrix.

7) (W_i) are the eigenvalues for the untransformed stiffness matrix $[k]$. Calculate the frequencies:

$$f_i = W_i / 2\pi$$

8) Eigenvectors $\{\phi_i\}$ must be transformed into the vectors $\{\bar{\Phi}_i\}$ of the untransformed matrix:

$$\{\bar{\Phi}_i\} = [\diagdown M^{*} \diagdown] \; \{\phi_i\}$$

9) Compute modal participation factors:

$$(R_i) = \sum_{j=1}^{n} \left[\bar{\Phi}_{ij}\right]^T \left[\diagdown M_{ij} \diagdown\right] \quad \ldots$$

10) The modal values of the inertia forces $\{P\}_i$ at the dynamic degrees of freedom for the i^{th} mode are given by:

$$\{P\}_i = (R_i) \; (a_i) \; [\diagdown M \diagdown] \; \{\bar{\Phi}_i\}$$

R_i = Participation factor for the i^{th} mode

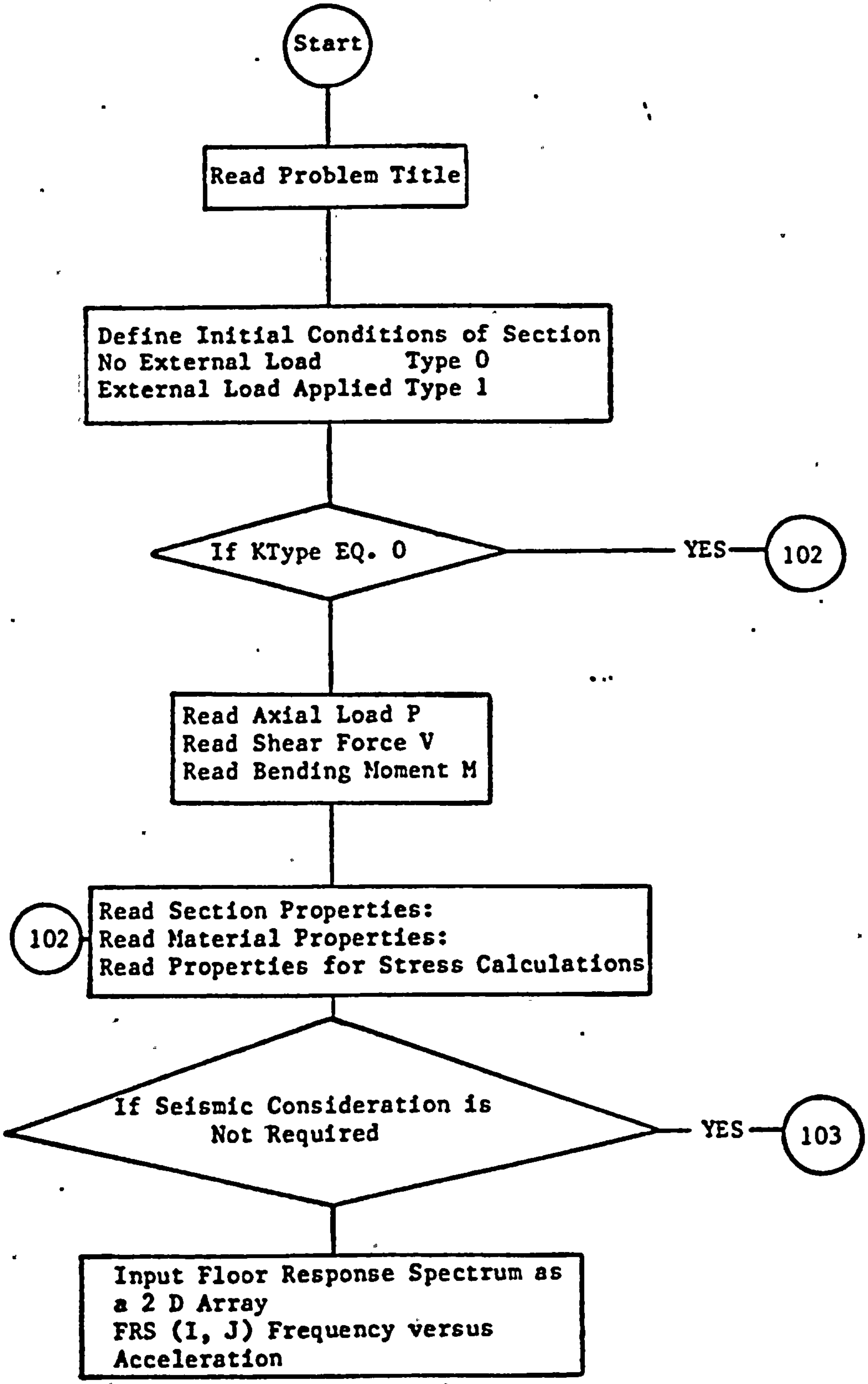
a_i = Acceleration for the i^{th} mode

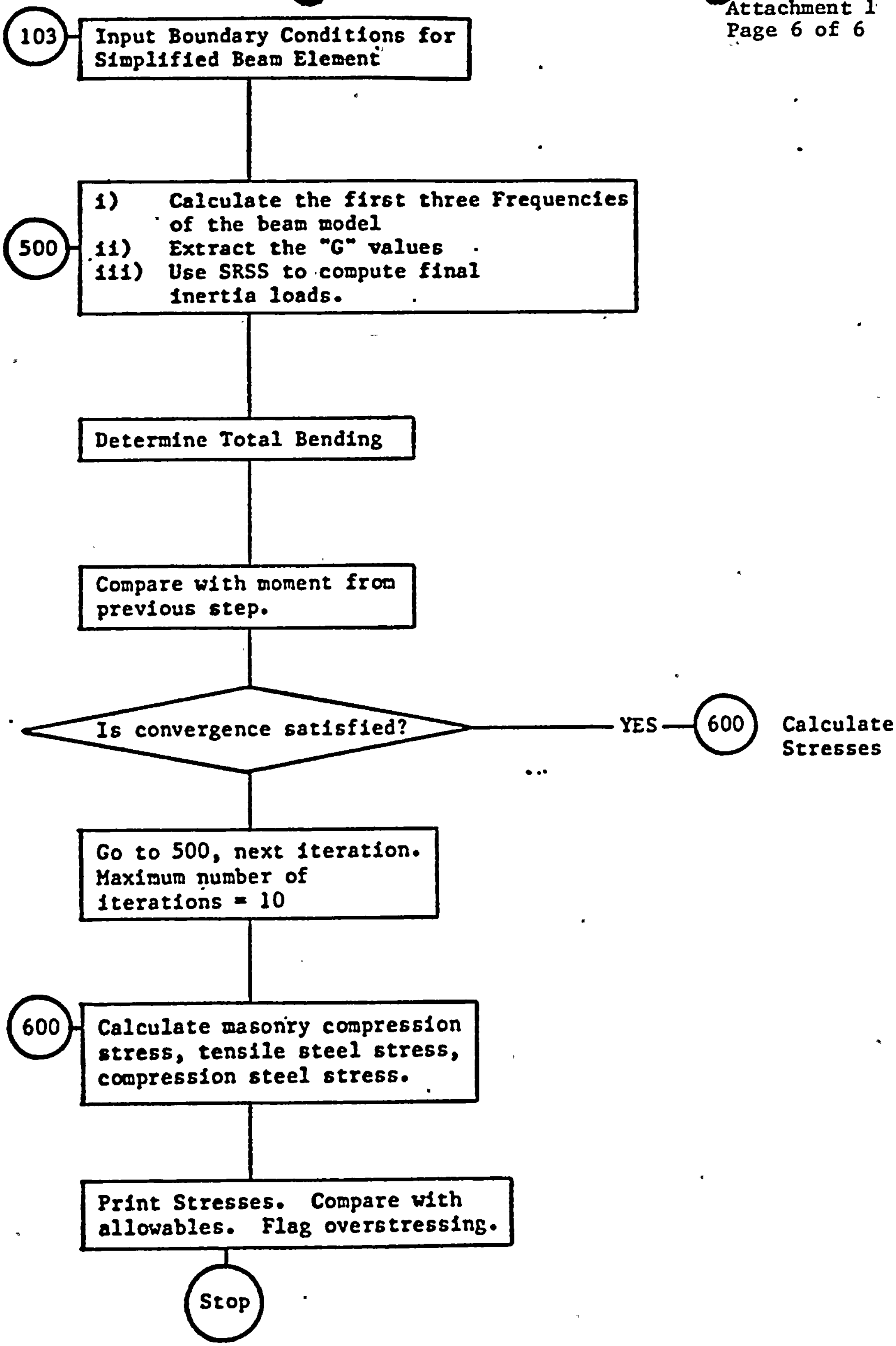
$\{\bar{\Phi}_i\}$ = Mode Shape for the i^{th} mode

11) Using the calculated inertial loads and the seismic moments, shear and the corresponding deflection are calculated using the SRSS method since the modes are not closely spaced.

3.0 COMPUTER PROGRAM

3.1 Flow Chart of the "Block Wall" Program




103
Input Boundary Conditions for Simplified Beam Element
500
i) Calculate the first three Frequencies of the beam model
ii) Extract the "G" values
iii) Use SRSS to compute final inertia loads.
Determine Total Bending
Compare with moment from previous step.
Is convergence satisfied?
YES
600
Calculate Stresses
Go to 500, next iteration. Maximum number of iterations = 10
600
Calculate masonry compression stress, tensile steel stress, compression steel stress.
Print Stresses. Compare with allowables. Flag overstressing.
Stop

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