Seismic Structural Response and Safety of a Large Fossil Fuel Steam Generating Plant

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Abstract

This is the Summary Report closing out NSF Grant No. ENV74-01575 A03 entitled "Seismic Structural Response and Safety of a Large Fossil Fuel Steam Generating Plant". The items covered are a summary of the major technical findings, abstracts of thesis, publication, list of scientific collaborators, and a list of research areas suggested by this study.

1. Introduction

The five major subsystems considered are:

i) Supporting structure and steam generator,

ii) High pressure steam piping,

iii) Stack,

iv) Cooling tower, and

v) Coal handling equipment.

The analysis of dynamic behavior was confined to the linear elastic range except for the Stack.

Each subsystem is remarkably complex. Before any modeling could be attempted it was necessary to acquire all the drawings describing each subsystem, and to study these drawings so that all elements could be identified and quantified. A substantial amount of time had to be devoted to this premodeling phase.

Numerous ad hoc simplifications that could be made in the dynamic model to simplify computations were readily apparent and also suggested by current practice. It was decided to ignore these initial simplifications in favor of retaining as much detail as possible so that the validity of the traditional simplifications could be assessed. This decision was fortunate in that certain features of the motion which are traditionally ignored turned out to be much more important than previously appreciated. This decision also required much more effort in constructing models than initially estimated, and limited in a substantial manner the extent of the investigation.

Once the dynamic behavior of each subsystem was known in some detail, a program was instituted to construct rational simples models where they were deemed necessary.

The complexity of each subsystem required the use of large computer codes from the start. These codes had to be acquired, implemented, and debugged. The computer code initially acquired and used was SAP IV. As the limitations of this code became apparent with use, NASTRAN was acquired and put into general use.

Major effort was devoted to Unit #3, Paradise, Kentucky, of TVA. This is a 1,200 MW coal fired unit. Only the steam generator and supporting structure was studied of the 600 MW coal fired unit of the Associated Electric Cooperative Power Company located at New Madrid, Missouri.

Section 2 describes the studies conducted in brief terms; it also presents the major technical conclusions and suggested areas for future research. Section 3 presents Abstracts of Theses, Section 4 presents lists of publications, and Section 5 lists the Scientific Collaborators.

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2. Technical Finding

I. Steam Generator and Supporting Structure

Two steam generators and their supporting structures were examined, as mentioned in the Introduction. A brief description follows:

The steam generator and it's supporting structure is one of the major subsystems of a fossil fuel steam generating plant. In certain phases of the analysis of their motion under seismic disturbances, the motion of these subsystems can be studied separately; however, the coupling between them requires that in the final analysis they be treated together.

The steam generator is a box in which fuel is burned, and the heat generated is extracted by the working fluid in tubes in the box walls, the primary superheater, the secondary superheater, the preheater, and a exonomizer, all of which are in the interior of the box. The weight of the steam generator and these internal components are supported by approximately 200 vertical hanger rods that are in turn supported by a grid of girders and beams at the top of the supporting structure. The steam generator is supported laterally by ties to the column of the supporting structure. Thus, the steam generator appears roughly as a compound three dimensional pendulum with elastic and geometric support provided by the vertical hanger rods from a deformable structure with added lateral connections to the same deformable structure.

The steam generator for Paradise Unit #3 is much larger than the one at New Madrid. The vertical support system is much the same. Because of the seismic code requirement at New Madrid, the lateral bracing is more extensive at New Madrid than at Paradise.

The supporting structure consists of large number of beams, girders, columns, and diagonal braces. The central section is open so it can contain the steam generator. Thus, the main columns as well as most of the secondary columns surround the plan area taken up by the steam generator. The columns rest upon a thick reinforced concrete slab or mat; the mat rests upon rock at Paradise and upon piles at New Madrid. In our study, the mat was assumed as fixed and subjected to horizontal translational (seismic) motion. Lateral and torsional stiffness in the supporting structure is provided by joint stiffness and diagonal bracing. There are more diagonal braces and joint stiffners at New Madrid than Paradise, again because of the seismic code requirement at New Madrid. A series of deep built-up girders and beams form the top of the central section of the supporting structure immediately above the steam generator. The vertical hanger rods that support the steam generator box and internal components are supported by this girder-beam unit. The supporting structure also contains coal storage, handling and processing equipment, air boxes, etc. Hence, the supporting structure surrounds and supports the steam generator, and the equipment needed to generate heat. For the New Madrid 600 MW power plant, the steam generator was modeled by 66 lumped masses interconnected by rigid and massless bars. The locations and the magnitudes of the masses closely represent the actual mass distribution of the steam generator. The 276 hanger rods were modeled by four equivalent rods. The lateral support of the steam generator is provided by 20 horizontal tie members connected to the joints of the supporting structure. The supporting structure was designed with hinged-joint conditions. It has 439 joints, 1085 horizontal and vertical truss elements, and 522 cross bracing members. In the finite element model, each of the 439 joints was assumed to have three displacement degrees of freedom. The total number of degrees of freedom is 1189. The dry weight of the steam generator is 17,200 kips and that of the supporting structure is 11,500 kips.

For the Paradise 1200 MW power plant, the structural model for the steam generator is very similar to that of the New Madrid plant. There are 277 hanger rods and 11 horizontal tie members. The supporting structure was designed with rigid-joint conditions. It has 415 joints, 875 beam and column elements, and 412 cross-bracing members. Each of the 415 joints was assumed to have two displacement (excluding the vertical displacement) and three rotational degrees of freedom. The total number of degrees of freedom is 1860. The dry weight of the steam generator is 24,100 kips and that of the supporting structure is 13,000 kips.

A natural frequency and corresponding normal mode analysis was made for the supporting structure of Paradise and New Madrid (See Report Seismic Structural Response of Steam Generators and their Supporting Structures"). The natural frequencies were confined to the ranged of seismic interest. It was found that the torsional motion was much more pronounced than anticipated (and usually assumed in conventional analyses); because of the extensive nonsymmetrical diagonal bracing. The first eight natural frequencies for New Madrid are higher than those of Paradise.

An analysis of the natural frequencies and corresponding normal modes was made for a rigid free steam generator supported by linear elastic vertical hanger rods which were in turn supported from a rigid fixed element (See Report "Derivation of Equation of Motion of a Free Rigid Body Steam Generator Supported by Vertical Elastic Rods"). This analysis revealed the complexity of the behavior of the vertical hanger rod system when supporting a general rigid body with eccentric mass center location and moments and products of inertia about coordinate axes through the mass center parallel to those used to define the elastic and geometric properties of the hanger rods. Superimposed compressive loads in the hanger rods were noted in the rods around the outer edges of the steam generator as the steam generator sways and twists. Torsional motion was again more pronounced than anticipated. Thirteen independent elastic constants summarize the elastic and geometric properties of the vertical hanger rods provided the steam generator is regarded as rigid and provided the hanger rods can withstand superimposed compressive loads. The above Report contains a derivation of the equations of motion for the specified system.

The Report entitled "Seismic Response of a Rigid Steam Generator Suspended from a Simplified Supporting Structure" contains a derivation of the equations of motion for a rigid steam generator taking into account the elastic and geometric properties of the vertical hanger rods, and linearly elastic lateral tie rods that connect the rigid steam generator to the deformable supporting structure. This basic derivation can be generalized in a number of different directions depending upon which assumptions are to be relaxed for a specific design. These equations were used to make an extreme value analysis of the motion of a two-dimensional steam generator and simplified supporting structure with lateral supports in different locations using 36 normalized seismic accelerograms. This extreme value analysis clearly revealed the strong dependence of the dynamic loads in the vertical hanger rods and the *location*, relative to the steam generator mass center, of the lateral supports.

The first Report referred to in this Section discusses the seismic motion of the steam generator and supporting structure. In particular, this discussion identifies those elements in the supporting structure, which have the highest dynamic loads. These elements can behave inelastically in a severe seismic disturbance.

The Report "Frequency Domain Structural Parameter Estimation" (also thesis od Dr. W. F. Krieger) addresses the problem of estimating the parameters of a structure based upon response data. The value of this work lies in its effort to correlate parameters values derived from engineering drawings with those that are actually observed from response data.

The major conclusions are as follows:

a) Torsional motion is more significant than usually assumed.

b) Supporting structure & SG must be modeled to account for 3D motion including torsion.

c) Dynamic model must account for the geometric and elastic behavior of the hanger rods.

d) Dynamic loads in vertical hanger rods are sensitive to location of horizontal tie rods. There appears to be optimum locations of horizontal tie rods that significantly reduce dynamic loads in hanger rods.

e) Variable length hanger rods may prove advantageous in controlling dynamic loads in hanger rods.

f) Torsional motion of SG with respect to its top supporting structure will significantly increase dynamic loads in hanger rods in four corners of SG.

g) The use of dampers as horizontal tie rods appears to offer advantages over elastic tie rods in reducing dynamic loads in hanger rods.

h) Supporting structure and SG should be configured in so far as possible to reduce torsion.

i) Reliable simple models can replace the model of actual supporting structure.

j) Vertical motion can be neglected in all but top of supporting structure.

k) If SG is supported significantly below top, elasticity of SG may have to be considered.

l) Model must include fact that vertical hanger rods cannot take compression if horizontal and vertical ground accelerations are above .15 g.

Suggested Areas for Future Research Are:

a) The effect of inelastic behavior of the heavily loaded members in the supporting structure.

b) Flexibility of the girder-beam unit and its influence on the dynamic loads in the vertical hanger loads.

c) Influence of inability of the vertical hanger rods to carry dynamic compressive loads above a certain value on the dynamic loads carried by the remainder.

d) Interaction of *flexible* steam generator with supporting structure with particular reference to dynamic loads carried by the lateral tie rods and the vertical hanger rods.

e) Optimum location and type of lateral supports connecting steam generator and supporting structure to minimize dynamic loads in lateral supports and vertical hanger rods.

II. High Pressure Steam Piping (Paradise Unit #3)

The high pressure steam pipe removes steam from the top of the steam generator and delivers it to the steam turbine inlet which is at the elevation of the foundation mat and below the steam turbine. The inlet conditions of the steam at the turbine are 1003° F. and 3800 psi. Except for the piping split just before the turbine inlet, the high pressure steam pipe has a 21.25 in. OD and 4 in. thickness. The material is A335P22, an iron based alloy with 2 ¼ Cr - ½ Mo. The vertical drop of the pipe is 215 ft. with two horizontal lengths (at top and bottom) of 52 ft. and 60 ft. The pipe is supported vertically from constant load hangers at a number of places.

The internal pressure and temperature and thermal expansion are the main sources of stress in the piping in the absence of seismic disturbances. The constant load hangers which support the pipe are arranged to interfere as little as possible with thermal expansion.

Lateral and vertical seismic disturbances cause the pipe to move in basically two ways. If the foundation mat and/or steam turbine and top of the steam generator moved together in a seismic disturbance, the pipe would move relative to its two ends as they moved because of the mass (inertia) of the pipe; part of the pipe motion comes from this source. However, the top of the steam generator does move relative to the foundation mat because of the flexibility of the supporting structure and the motion of the steam generator relative to the girder-beam element at the top of the supporting structure; this relative motion involves translation and rotation. Hence, the dynamic stresses in the high pressure steam piping due to seismic disturbance arise from inertia and relative motion of the top connection to the steam generator and the bottom connection to the steam turbine.

In the structural modeling, 29 pipe elements (in general, one element between two supports except at the bends) were used. Each pipe element has six degrees of freedom at each end: three displacements and three rotations.

The Report entitled "Dynamic Response of a High Pressure Steam Pipe in a Fossil Fuel Power Plant" describes the study conducted. Natural frequencies and the corresponding normal modes are estimated for a fixed-fixed and a frame-pipe system. The majority of the normal modes of the frequencies in the range of interest are in the horizontal direction. The response of the pipe fixed to the foundation mat at the bottom and fixed to a two-dimensional simplified structure representing the steam generator and its supporting structure at the top was studied under a horizontal seismic disturbance at the foundation mat. Significant dynamic stresses were observed near ends of the pipe even using this two-dimensional simplified structure which did not permit torsional motion of the steam generator.

The major conclusions are:

a) Finite element models of piping in considerable detail are practical and should be used.

b) Linear and angular motion of point where steam piping and SG join can cause significant increases in dynamic stresses in steam piping, and should be taken into account.

c) It is essential to consider the high pressure steam piping and the steam generator and its supporting structure together in a three-dimensional setting if adequate estimate of dynamic stresses is to be obtained.

Suggested Future Areas of Research Are:

a) Make an extreme value analysis of the seismic response of the high pressure steam pipe connected at its top to a three-dimensional model of the steam generator and its supporting structure.

b) Determine if there is an optimum method for supporting and configuring a high pressure steam pipe so that dynamic stresses due to seismic disturbance can be kept below a specific maximum and consistent with other requirements.

III. Stack (Paradise Unit #3)

The stack removes the spent products of combustion (flue gas) from the steam generator and disperses them at a suitable high elevation.

The stack is approximately 823' tall. It consists of a reinforced concrete liner which conducts the flue gas and a reinforced concrete outer shell, which provides wind shielding for the liner. The stack rests upon a reinforced concrete foundation that is based upon rock. The base OD of the outer shell is 72 ft., and it tapers to an OD of 38.5 ft. at the top. The liner is approximately 12 ft. less in diameter than the outer shell. The flue gas enters the stack through a pair of rectangular openings that are approximately 30 ft. above the base of the stack. The outer shell and liner are not connected.

Two kinds of structural modelings were used for both the inner and outer chimneys: a gross model and a local model. The gross model consists of eight pipe elements with a total of 48 degrees of freedom for modeling the whole chimney. The local model consists of 70 quadrilateral plate elements with 840 degrees of freedom for modeling a half of the pipe element at the base that contains a flue opening for stress concentration analysis.

An analytical investigation of the response of both the liner and the outer shell is presented in the Report "Theoretical Study of the Dynamic Response of a Chimney to Earthquake and Wind". Natural frequencies and normal modes are found for both shells assuming fixed base in the frequency range of interest. A dynamic analysis was then performed and it is found that the concrete of the outer liner will crack under the seismic disturbance considered.

The major conclusions are:

a) Finite element model of chimney gives adequate results.

b) Inelastic behavior of concrete must be included.

c) Vertical ground motion does not appear to cause significant response.

The Suggested Areas for Further Research Are:

a) Determine via extreme value repsonse analysis extent of cracking in concrete.

b) Determine if it is possible to design stack so that cracking does not endanger its future use.

IV. Cooling Tower (Paradise Unit #3)

The cooling tower cools the condenser coolent (water). There are three cooling towers at Paradise of identical design and construction.

The cooling towers are reinforced concrete hyperboloid shells of revolution supported by 80 inclined reinforced concrete columns Each tower is 441' high and the vertical height of the inclined columns is 40'. The base OD is 314.9', throat OD is 187.0', and the top OD is 203'. The columns rest on footings which go to bed rock. The shell thickness varies from 24"at the base, to 7" at the throat, to 9" at the top. The top has a reinforcing ring of rectangular cross section that provides a walkway. The columns have a diameter of 25".

A large cooling tower is vulnerable to wind and seismic disturbances. Horizontal seismic disturbances tend to overturn the tower and flatten the shell; vertical seismic disturbances tend to excite longitudinal vibrations. Of the two types of disturbances, lateral acceleration is the more severe.

Several different half-shell mesh configurations were used to model the Paradise cooling tower. These element mesh sizes include: 4x10 (345 D.O.F.), 8x10 (573 D.O.F.), 9x10 (654 D.O.F.) and 9x10 (918 D.O.F.). The 918 D.O.F. model differs from the others in that it uses two beam finite elements to represent each individual supporting column except for the column at one edge of the half-shell ($\theta = 0^\circ$). This particular column is formed by six beam elements in order to find detailed stress information along the column length. All the above models feature beam elements to form the top ring-beam of the shell, orthortopic quadrilateral plate elements with a triangular variation at the base to form the shell, and beam elements to form the discrete column supports.

The natural frequencies and corresponding normal modes were calculated and the modes are displayed in Report "Theoretical Study of Earthquake Response of the Paradise Cooling Tower". (Ph.D. Thesis of C. Gran) Seismic response studies were then made for horizontal ground motion.

The principal findings are:

a) All but bottom ¼ of height of shell can be modeled as membrane finite elements.

b) Columns that support cooling tower carry significant dynamic loads.

c) Interaction of individual columns and lower portion of shell must be examined in detail by means of appropriate shell finite elements in bottom ¼ of shell.

d) Inelastic behavior of material may have to be included if ground accelerations are significant especially in columns and bottom of shell.

Suggested Areas for Future Research Are:

a) Influence of inelastic behavior in bottom of shell and top of columns on dynamic stress under horizontal ground motion.

b) Extent of area in which cracking of concrete might occur in strong horizontal ground motion.

c) Determine if cracking uncovered in b) can be repaired at reasonable expense.

d) Extreme value response analysis is needed for design purposes.

V. Coal Handling Elevator (Paradise Unit #3)

This study is contained in the Report entitled "Theoretical Study of Earthquake Response of a Coal Handling Elevator Supporting Structure" (Ph.D. Thesis R. C. Morehead).

The coal handling elevator permits the stock piling of coal for future use in the steam generator. It consists of an inclined truss approximately 300' long which starts at ground level and of approximately 100', and a horizontal section approximately 250' long. This structure is supported on one central tower with two bents under the inclined section and one bent under the horizontal section.

The elevator is vulnerable to horizontal and vertical seismic disturbances.

The horizontal and inclined truss consists of 49 bays which were modeled by 956 truss bar elements. The bents and the supporting tower were modeled by 81 beam elements. The reinforced conrete walkway beneath the elevator was modeled by 34 quadrilateral orthotropic plate finite elements, The complete model of the structure has 232 joints, over 1000 finite elements, and about 100 lumped masses. The assembled system results in 714 degrees of freedom and has a bandwidth of 126.

Natural frequencies and corresponding normal modes were calculated by modeling the structure in detail. The normal modes are displayed in the Report. The seismic response of the details of the structure was studied. A motion picture of the response also was made.

The major conclusions are:

a) Finite element analysis of all members is practical.

b) May be necessary to account for wave motion of ground since support points are far apart.

c) Lateral flexibility is high in Paradise and significant response could develop if ground motion is in right direction.

d) Under a strong seismic disturbance the elevator will be damaged.

Suggested Areas for Future Research Are:

a) Investigate dynamic response when the inelastic behavior of the highly loaded members are taken into account.

b) Determine if the structure will collapse in a strong earthquake.

VI. Simple Models

The possible use of simple models was considered for each of the substructures considered. It was found that it is practical (with NASTRAN) to model the high pressure steam pipe, stack, cooling tower, and coal handling elevator in detail and study their seismic response without recourse to simple models. The computer time was not excessive in any case.

A simple model for the steam generator and its supporting structure is necessary. The results of this study are in the Report entitled

The major conclusions are:

a) Methodology is developed for complex structures.

b) First 5 mf's and modes agree well with complex structure information.

c) Response of simple models to seismic disturbances agrees well with response of complex structure.

d) From response of model, can get stresses and deflections in complex model.

e) Methodology can be extended to provide 3D simple models.

The extension of the methodology to three-dimensional structure is important and is in progress.

3. Abstract of Thesis

ABSTRACT

Krieger, William Fredrick. Ph.D., Purdue University, December 1977. Frequency Domain Structural Parameter Estimation. Major Professor: John L. Bogdanoff.

A new methodology for estimating structural parameters recursively in the frequency domain is developed. Maximun likelihood and Bayesian estimates are obtained, as are the appropriate confidence regions. In a strict sense the methodology requires a linear, viscously damped system; however, it may be possible to apply the methodology in an approximate sense to certain nonlinear and/or nonviscously damped systems. Output measurement noise and the effects of certain unmeasured inputs are allowed.

A computer simulation example is carried out so that the performance of the new methodology can be evauluated. Noise levels, the number of replications, statistical assumptions, and the number of outputs simultaneously considered are varied. The methodology is then applied to a 138 kV Air Core Line Trap structure, however, results are inconclusive due to the lack of applicability of a linear, viscously damped model. Overall results are favorable, however, application of the methodology of large degrees of freedom finite element models will require certain efficiency modifications.

ABSTRACT

Gran, Carl S., Ph. D., Purdue University, September 1978. The Seismic Response of a Column-Supported Cooling Tower. Major Professor: Henry T. Y. Yang.

A cooling tower in the 1200 MW Fossil Fuel Steam Generating Power Plant at Paradise, Kentucky (Tennessee Valley Authority) is studied. Half of the shell is modeled using orthotropic quadrilateral flat plate finite elements. The supporting columns and top ring beam are modeled by beam finite elements.

The time-history response of 30 seconds to the North-South acceleration component of the May 18, 1940 El Centro earthquake is computed by the technique of modal superposition.

A response spectrum analysis is used to ascertain the maximum response of the first three eccentric modes with 4% critical damping. From a RMS estimate of the total maximum response, forces and stresses in the shell and columns are obtained. The contribution of gravity loading is included.

A 28 d.o.f., double-curved, four corner membrane finite element is developed for the analysis of membrane shells of revolution. The element possesses three rigid-body modes. The element is evaluated by a variety of static and free vibration examples that have alternative solutions. Of particular interest are the cooling tower examples. The element is shown to have excellent convergence characteristics and the results are in excellent agreement with alternative solutions.

ABSTRACT

Baig, Mirza Irfan, Ph. D., Purdue University, May 1978. Seismic Structural Response Analyses of Steam Generators and their Supporting Structures of a 1200 MW and a 600 MW Power Plant. Major Professor: Henry T. Yang.

The seismic response studies of the steam generators and their supporting structures of a 1200 MW and a 600 MW fossil fuel steam generating plants have been carried out using finite element models. The 1200 MW steam generator has been modeled by 48 lumped masses connected by rigid massless bars and the columns, the beams and the girders of its supporting structure have been modeled by 878 three-dimensional beam finite elements. The bracings, the hanger rods and the horizontal tie bars have been modeled by 412 truss finite elements. The two concrete working floors have been modeled by plane finite elements. Five degrees-of-freedom have been assigned to each nodal point of the model. The 600 MW steam generator has been modeled by 66 lumped masses connected by rigid massless bars and its supporting structure has been modeled by 1607 three-dimensional truss finite elements. Three degrees-of-freedom have been assigned to each nodal point of the model.

The seismic response analyses of the two systems have been carried out in two parts. The first part involves the determination of fundamental frequencies of free vibration and the associated mode shapes. The second part involves the determination of modal member of both structures. The

ratio of axial stress to the Euler buckling stress has also been obtained for each truss member of both the structures.

It is observed that for the 1200 MW steam generator-structure system, 277 out of 1290 structural members exceed elastic limit while 85 structural members exceed the ultimate stress. The vulnerable components of this structural system are the horizontal tie bars and the columns supporting the airheater. For the 600 MW steam generator-structure system, 157 structural members out of 1607 exceed the elastic limit and 57 exceed the ultimate stress. The vulnerable components of this structural system are a few horizontal tie bars and the columns in the rear of the structure.

ABSTRACT

Shiau, Le-Chung, Ph. D., Purdue University, August 1978. Theoretical Study of the Dynamic Response of a Chimney to Earthquake and Wind. Major Professor: Henry T. Y. Yang.

An analytical investigation of the response of a chimney to earthquake and wind is presented. The 823-foot tall chimney is modeled using Bernoulli-Euler beam finite elements. The modal superposition method is used for analyzing the elastic response while the numerical direct integration method is used to solve the equations for the inelastic response. A mathematical model that enables one to predict the vortex-excited resonant responses of two cylinders in line in the wind direction is developed.

For the elastic case, the cracks developed in the chimney and the effect of the shear deformation are considered. Several assumed values of the critical damping are included in the analysis. The stress distributions around the flue openings are found by using quadrilateral plate finite elements. A comparison of the results between time history analysis and response spectrum analysis is made.

For the inelastic case, the material is assumed to have elastic-perfectly plastic behavior. Moment-curvature equations for a pipe-type section are derived and combined with the Wilson-Θ method to predict the inelastic dynamic response of the chimney.

For the dynamic response of cylinder to wind, a modified van der Pol equation is employed as the governing equation for the fluctuating lift on the cylinder and is combined with the equation of motion for the cylinder. The results are compared with available experimental data.

ABSTRACT

Chen, Chun-Chieh, Ph. D., Purdue University, August 1978. Simple Models for Computing Dynamic Responses of Complex Frame Structures, Major Professor: Dr. C. T. Sun.

A simple shear beam model and a Timoshenko beam model have been developed for dynamic analyses of complex frame structures. Explicit formulas have been derived for computing the equivalent shear and bending rigidities in terms of th member dimensions and material properties of the original frame structure. The simple models are evaluated by comparing the simple model solutions with the solutions obtained from using full scale finite elements in free vibrations of plane frames. It is found that the simple models yield very accurate natural frequencies as well as mode shapes for the lower modes. When the structure is relatively tall as compared with its lateral dimension or when diagonal bracings are present, the Timoshenko beam model is more superior to the shear beam model. A model of axial member for the longitudinal motion is also derived for heavily braced structures for which the longitudinal mode might occur among the lower modes. The shear beam model is employed to compute the natural frequencies and the corresponding mode shapes of the fossil fuel power plant of Unit #3 of TVA at Paradise, Kentucky. The first two frequencies are found to be in good agreement with the finite element solutions. The simple models are also used to compute transient dynamic responses and dynamic internal member stresses of the original structures

subjected to earthquake disturbances. The time history responses of a frame structure in the TVA power plant subjected to the 1940 El Centro N-S and/or E-W acceleration components are also investigated with or without damping. The use of simple models appears to be even more economical in computing time in the analysis of transient response as compared with the full scale finite element modeling.

Theoretical Study of the Earthquake Response of a Coal Handling Elevator Supporting Structure

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ABSTRACT

This study is concerned with determining the seismic response of the supporting structure for coal handling elevators No. 28 and No. 29 at TVA's steam power generating plant in Paradise, Kentucky. These elevators feed live piles No. 3 and No. 4, respectively.

The supporting structure for the coal conveyors is a complex three-dimensional system. An adequate model for analyzing the dynamic behavior of the system, required the use of over 1000 three-dimensional truss, beam, and plate finite elements and approximately 100 lumped masses. The assembled system has 714 degrees of freedom.

The analysis has the following objectives:

a) Determine the basic dynamic properties of the system, i.e., the natural frequencies and their corresponding normal modes.

b) Perform a response spectrum analysis to determine the necessary number of modes to be included in an earthquake time-history response analysis and to provide a means of checking the time-history calculations.

c) Determine the response of the coal handling equipment to the North-South component of the El Centro, 1940 earthquake using the mode superposition technique and investigate the effect of viscous damping on the response.

d) Identify the vulnerable members of the structure.

e) Utilize computer graphics techniques for data checking, displaying results, and as a medium for gaining insight into the nature of the structure's dynamic behavior.

The free vibration analysis, the earthquake response spectrum analysis, and the earthquake time-history response analysis, were carried out with an existing structural analysis program, SAP IV. To enchance the entire analysis process, a three-dimensional perspective projection plotting program was developed. This program has the capabilities of displaying either the basic structural model of or superimposing a deformed structural configuration, such as a mode shape, upon the original undeformed configuration. A number of other programs were required to further analyze and display the results.

DYNAMIC RESPONSE OF A HIGH PRESSURE STEAM PIPE IN A FOSSIL FUEL POWER PLANT

prepared by

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ABSTRACT

The dynamic behavior of the high pressure steam pipe in the fossil fuel power plant of Unit #3 of TVA at Paradise, Kentucky is investigated. Both natural vibration and the dynamic response of the piping system subjected to a ground acceleration identical to the NS component of the ground acceleration in the El Centro earthquake are studied. In the analysis, the pipe is assumed to be fixed at both ends in one case; in the other case, the supper end of the pipe is connected to a shear beam that represents the boiler frame structure. The results are compared. The effects of damping and stiffness are also investigated.

4. Publications to Date

[1] Yang, T.Y., Sun, C.T., Lo, H., Kayser, K.W., and Bogdanoff, J.L., "Some Results on Dynamic Characteristics of Major Components of 1200 MW Fossil Fuel Steam Generating Plant", ASME Paper 76-JPGC-Pwr-11, IEEE-ASME Joint Power Generation Conference, Buffalo, N.Y., Sept. 1976.

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