Methodology for Seismic Qualification of Nonstructural Components

Viral N. Talati¹ M.Y. Patil ² Chirag P. Mistry³ M. M. Kadri⁴
¹, ³, ⁴ P.G. Student ² Associate Professor
¹, ², ³, ⁴ Mechanical Engineering Department
¹, ², ³, ⁴ L.D. College of Engineering, Ahmedabad

Abstract—Now a days any Plant, Manufacturing Shop, Assembly shop etc. has variety of structures, system and equipment comprising of primary civil structure, secondary supporting structure, supporting systems and equipment viz. tanks, vessels, heat exchangers, piping, supports, valves, pumps, fans, blowers, motors, compressors, diesel generator etc. Seismic Analysis of Plant structural is to calculation of the response of structure to earthquakes. It is part of the process of structural assessment and retrofit in regions where earthquakes are prevalent. Seismic qualification of various systems generally done by two methodologies (1) Qualification by Testing; in which Qualification is performed by shake table testing, however shake table testing is not feasible for the systems with excessive weight and large size. (2) Qualification by analytical methods. In this method Analytical models is required to be developed for assembly/component. Generally Qualification done by Analysis which FEA model is and checked under static condition after applying sufficient boundary condition and loading. Modal analysis done to find the natural frequency of the system. On the basis of that Harmonic and Transient analysis done and visualize the response of system under given condition in form of stress, deformation etc.

Key Words: - Seismic Qualification of Nonstructural Component, Floor response spectrum, Time History Analysis, Shake Table Testing, FEM Analysis

I. INTRODUCTION

Nonstructural building components are elements within or attached to buildings to provide them within essential services and functions. Nonstructural refers to the portion of buildings and facilities that do not perform structural function—that is, that do not resist vertical or internal loads. These components are not a part of the building structural system, and are not designed to contribute to resistance to earthquake force. Nonstructural components of building include:

- Architectural components: Parapets, claddings, partitions, stairways, lighting system, suspended ceilings, etc.
- Mechanical and electrical equipment: pipes and ducts, Industrial fan, escalators, central control panels, transformers, emergency power systems, fire protection systems, machinery, etc.
- Building contents: books and shelves, furniture, file cabinets, storage racks, etc.

In several past earthquakes, it has been documented that damage to nonstructural building components can have a great effect on the safety of occupants and functionality of facilities, and loss of property. Therefore, nonstructural elements should be designed to resist the seismic forces or seismic relative displacements depending on their nature. When a building is subjected to an earthquake ground motion, the building can amplify this motion, resulting in floor accelerations higher than the peak ground acceleration (PGA). Equipment is the mechanical, electrical, or other components required for system functionality. These components are normally heavy and sometimes large in size. Several conditions can increase the seismic vulnerability of this equipment. If not properly restrained, equipment, machinery, and fluid tanks will tend to slide. Massive objects in motion during earthquake can injuries and damage adjacent objects. The motion can also damage connected piping, ductwork and electrical conduits, which in turn may lead to other. Serious damage caused by fires, hazardous fluid spills and water leaks. Equipment mounted on vibration isolators is particularly vulnerable because isolation permits resonance during earthquake motions making equipment more difficult to restrain. Tall, slender objects with high center of gravity can fall over if not adequately anchored. Failure of equipment and the debris caused by falling object could critically affect the performance of vital facilities such as emergency command centers, fire stations, hospitals, power stations and water supply plants. In view of the importance of protecting the integrity of nonstructural components during seismic events, so there are needs to carry out additional research studies to develop reliable performance based design criteria for nonstructural components and develop methodology and procedure for the Qualification of system. [1].

II. PAST WORK AND RESEARCH DONE ON METHODOLOGY OF SEISMIC QUALIFICATION OF NON-STRUCTURAL COMPONENT

The seismic analysis should be based on the Floor Response Spectra derived from the response of main primary structural system. The structure is evaluated by time history method to arrive at the floor history and floor response spectra. These floor response spectra are further used for the design or evaluation of the floor mounted nonstructural components.

Design consideration of seismic force is accounted at the time of design as well as after designing of Component, it tested for its functionality. Some of the researcher’s work presented below,

A. A.C.Pal (1992) Publish paper on Seismic analysis and Design of Nuclear Power Plant. In his paper he shows that an Assessment of seismic analysis and design methodologies of nuclear power plant designed prior to or during the 1970 and specially located in the eastern United States (EUS) is made. Analysis of NPP involves multiple operations in stage starting from generation of free field
response spectrum to floor spectrum generation to qualification of supporting structure. Due to lack of analytical technique and field data from earthquake, the analysis and design of these plants were performed with conservative assumption as new data on earthquake is available and new numerical analysis technique are applied to reanalyze these plants, it is consistently revealed that the structure and components are adequate to resist the imposed seismic/dynamic loading.

B. C.G Duff et all (1992) published paper on Seismic Qualification of Nuclear Power Plant by Inspection. In his paper, he told In Canada, seismic surveys of CANDUPWH Nuclear Power Plant are now pre requisite to licensing. Such survey provides greater confidence that nuclear plant can safely survive a design basis earthquake. In U.S.A, There is no mandatory requirement for such survey have been used to qualify Nuclear Facility where the original design did not consider current seismic design level or method of analysis. Paper consider the possible application of this approach to the seismic requalification of existing U.S Nuclear Power Plant for higher Earthquake levels or analytical techniques different from those originally specified.

C. Pentti Varpasuo(2013) published paper on Seismic design and analysis of nuclear power plant structures. In his paper, The seismic design and analysis of nuclear power plant (NPP) begin with the seismic hazard assessment and design ground motion development for the site. The following steps are needed for the seismic hazard assessment and design ground motion development.

1) the development of regional seismo-tectonic model with seismic source areas within 500 km radius centered to the site. Item the development of strong motion prediction equations.
2) logic three development for taking into account uncertainties and seismic hazard quantification.
3) the development of uniform hazard response spectra for ground motion at the site.
4) simulation of acceleration time histories compatible with uniform hazard response spectra.

The following phase two in seismic design of NPP structures is the analysis of structural response for the design ground motion. This second phase of the process consists of the following steps.

- development of structural models of the plant buildings.
- development of the soil model underneath the plant buildings for soil-structure interaction response analysis.
- determination of in-structure response spectra for the plant buildings for the equipment response analysis.

In the third phase of the seismic design and analysis the equipment is analyzed on the basis of in-structure response spectra. For this purpose the structural models of the mechanical components and piping in the plant are set up. In large 3D-structural models used today the heaviest equipment of the primary coolant circuit is included in the structural model of the reactor building. In the fourth phase the electrical equipment and automation and control equipment are seismically qualified with the aid of the in-structure spectra developed in the phase two using large three-axial shaking tables. For this purpose the smoothed envelope spectra for calculated in-structure spectra are constructed and acceleration time is fitted to these smoothed envelope spectra.

D. D. Witchen (2005). Published paper on Seismic Analysis of Wind Turbines in the Time Domain. In his paper, The analysis of wind turbine loading associated with earthquakes is clearly important when designing for and assessing the feasibility of wind farms in seismically active regions. The approach taken for such analysis is generally based on codified methods which have been developed for the assessment of seismic loads acting on buildings. These methods are not able to deal properly with the aero elastic interaction of the dynamic motion of the wind turbine structure with either the wind loading acting on the rotor blades or the response of the turbine controller. This article presents an alternative approach, which is to undertake the calculation in the time domain. In this case a full aero elastic model of the wind turbine subject to turbulent wind loading is further excited by ground motion corresponding to the earthquake. This capability has been introduced to the GH Bladed wind turbine simulation package. The software can be used to compute the combined wind and earthquake loading of a wind turbine given a definition of the external conditions for an appropriate series of load cases.

E. Myung Jo JHUNG et all (2010) published paper on study on the Dynamic Response of Mechanical Component to Earthquake. In this paper, Presented in this study is a theoretical background developed in ANSYS for the time history analysis due to seismic excitation. The effect of the base excitation types on the responses is investigated by comparing response histories between various excitations. In addition to the base excitations, acceleration time histories are applied to the whole model with a base fixed, which is a traditional case used in the transient analysis for the seismic excitation. Also, the response spectrum analysis is performed to generate stresses. All the results of these analyses are compared with each other and the analysis characteristics are addressed for the responses such as displacement, velocity, acceleration, response spectrum and stress with respect to the various excitation types for the seismic analysis. Finally, the applicability of the analysis types is suggested for obtaining the dynamic responses of the mechanical component due to earthquake. Three types of excitations are applied to the base of the structure for the seismic analysis and their responses are compared with each other. Also, accelerations are applied to the whole structure with a base fixed, and response spectrum analysis is performed. The responses due to these excitations are compared, generating the following conclusions when using ANSYS for the time history analysis due to seismic excitations as follows: The only acceptable excitation type is to apply the acceleration time histories to the whole model with a base fixed. When acceleration time histories are applied as a base excitation, the rigid body motion may appear which should be carefully investigated. When velocity or displacement time histories are applied as a base excitation, the corresponding velocity, acceleration, or response spectra generated during the analysis may not be correct. It is not recommended to use the command that defines DOF
constraints at nodes for the time history analysis due to seismic excitation.

F. Marcelo Oropeza et al (2010), published paper on the Seismic response of non-structural components in case of nonlinear structures based on floor response spectra method. In this paper, investigates the response of nonstructural components in the presence of nonlinear behavior of the primary structure using floor response spectra method (FRS). In his paper, The effect of several parameters such as initial natural frequency of the primary structure, natural frequency of the nonstructural components (subsystem), strength reduction factor and hysteretic model have been studied. A database of 164 registered ground acceleration time histories from the European Strong-Motion Database is used. Results are presented in terms of amplification factor and resonance factor. Amplification factor quantifies the effect of inelastic deformations of the primary structure on subsystem response. Resonance factor quantifies the variation of the subsystem response considering the primary structure acceleration. Obtained results differed from precedent studies, particularly for higher primary structure periods. Values of amplification factor are improved. Obtained results of resonance factor highlight an underestimation of peak values according to current design codes such as Euro code 8. Therefore a new formulation is proposed.

G. M. B. Sharif et all(2011) published paper on SEISMIC EVALUATION OF EQUIPMENT SUPPORTING STRUCTURES. In this paper, Industrial buildings are commonly subjected to forces induced by machine vibrations, earthquake and wind loads. There are number of equipment which have vibrating actions and at the same time tall enough to withstand the wind and earthquake forces. This study deals with the37m high vessel supported on two store RC frame. The structure was modeled using STAAD PRO 2007. Equivalent lateral forces for model structure were calculated according to seismic provisions for Lahore. The anchorage mechanism between vertical vessels and table top foundation is studied in detail for earthquake induced loading. Anchorage mechanism was designed on ductile failure of stud and bolt. This study revealed that seismic forces on equipment supporting structures are 20 to 30 percentage more than ordinary structures due to low lateral force resistance factor. Design of heavy equipment is primarily governed by large overturning moments. The tilting effect due to heavy equipment loads is catered by proper anchorages to ensure the safe performance under the severe earthquakes. The conclusions will also be useful for the structural designers involved in the design of such industrial buildings.

H. A.T. Myers et all (2012) published paper on investigate Evaluation of the Seismic Vulnerability of Tubular Wind Turbine Towers. In his Paper, paper presents an overview of some of the important considerations for the reliable evaluation of the seismic risk to modern wind turbine support towers. These considerations include:

(1) Turbine specific characterization of the susceptibility of the tower cross-section to local buckling,
(2) site specific assessment of both the strength and characteristics of ground motions, and (3) consideration of the response during the operational versus parked condition. The paper also presents the results from a brief analytical study which showed that the spectral Characteristics of the ground motion can have a significant impact on the fragility of a wind turbine. For this study, the fragility of one particular 80m, 2.4 MW wind turbine was shown to be the highest for soft soil ground motions and the lowest for firm soil ground motions with pulse-like ground Motions having an intermediate fragility. Additionally, the analysis shows that the vulnerability is also dependent on the specific turbine design, even for turbines of similar height. More research work is required and some of it underway to more comprehensively addresses the seismic vulnerability of tubular wind turbine towers and wind farms, in general.

I. Ian Prowell (2009) published paper on Experimental and Numerical Seismic Response of a 65 kW Wind Turbine. In his paper he published a full-scale shake table test is conducted to assess the seismic response characteristics of a 23 m high wind turbine. Details of the experimental setup and the recorded dynamic response are presented. Based on the test results, two calibrated beam-column finite element models are developed and their characteristics compared. The first model consists of a vertical column of elements with a lumped mass at the top that accounts for the nacelle and the rotor. Additional beam-column elements are included in the second model to explicitly represent the geometric configuration of the nacelle and the rotor. For the tested turbine, the experimental and numerical results show that the beam-column models provide useful insights. Using this approach, the effect of first-mode viscous damping on seismic response is studied, with observed experimental values in the range of 0.5-1.0 percent and widely varying literature counterparts of 0.5-5.0 percentage. Depending on the employed base seismic excitation, damping may have a significant influence, reinforcing the importance of more accurate assessments of this parameter in future studies. The experimental and modeling results also support earlier observations related to the significance of higher modes, particularly for the current generation of taller turbines. Finally, based on the outcomes of this study, a number of additional experimental research directions are discussed.

J. M. Waqas Anjum, et all (2012) investigate the Seismic Analysis of Electronic Cabinet using ANSYS. In his paper, Structural analysis using Finite Element Method gives a preliminary assessment of dynamic behavior of mechanical structures in order to establish the guidelines for designing the experiment. The main objective of this study was to develop a methodology of seismic analysis of electronic cabinets using ANSYS, FEA model of Electronic cabinet is developed then natural frequency of the cabinet is find by Model analysis. Generally, two approaches i.e. transient analysis and response spectrum analysis are adopted for the seismic analysis in ANSYS. Since, the given loading was in time domain, therefore, transient structural analysis was preferred for the detailed dynamic investigation of electronic cabinet. In this paper the cabinet was modeled with Beam188 and its modal analysis was performed rendering the fundamental natural frequency of 8.94Hz, sufficiently close to the experimentally measured frequency of 8.33Hz. Subsequently, Transient analyses were performed for horizontal components of ground motion that resulted in

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peak displacement of 37mm and 28mm at the top of the cabinet which were in good agreement with experimentally measured maximum displacement of 40mm and 30mm at the same location, respectively. In addition, peak accelerations obtained from transient analyses were 0.6g and 0.82g while the experimentally measured peak accelerations were 0.8g and 0.89g respectively. It can be concluded that seismic analysis performed in ANSYS produced equivalently reliable assessment of the dynamic behavior of electronic cabinets. Although, ANSYS simulations cannot exclude the experimentations but greatly reduce the design of experiments where time and cost do not allow experimentations.

K. Hyung-Bin Im, et all (2012), published paper on seismic Analysis of an Axial Blower using ANSYS. In this paper, A seismic analysis is one of crucial design procedures of an axial blower used in nuclear power plants. The blower should withstand and operate under emergency situations such as earthquake. For the seismic analysis, they performed modal analysis and then evaluated Required Response Spectrum (RRS) from the given Floor Response Spectrum (FRS). Prior studies have been done similar to this method .A finite element model of the blower is established by using commercial FEM software, ANSYS. After the finite element modeling, natural frequencies, mode shapes and the participation factors are obtained from the modal analysis. The RRS is acquired by numerical approach on the basis of the principle of mode superposition. They were able to verify the structural safety of the axial blower and confirmed the validity of the present seismic analysis results. In this paper, the axial blower was modeled and undergone mode analysis in ANSYS. Data from mode analysis, such as modal participation factor and effective mass were used to determine frequency response function and then modal coordinate function. Then superposition method is applied to yielded modal coordinate function in order to find RRS. By obtaining RRS, it was possible to determine the safety of the axial blower used in the nuclear power plant. In this paper, RRS of the axial blower exhibits stable condition and didn’t exceed 10G under most earthquakes. However, when Y-direction frequency is above 50 Hz, RRS value exceeds 10G. It is known that frequency of the earthquake waves seldom go above 33 Hz, but the earthquake safe should be thought. As the axial blower is weak in Y-direction frequency, it is desirable to reinforce the mounting bolt to the surface in order to ensure safety.

L. Mohd Zubair Nizami, Et All (2013)[13], investigates EVALUATION OF STATIC AND DYNAMIC ANALYSIS OF A CENTRIFUGAL BLOWER USING FEA. In his paper, His work aims at examining the choice of composites as an alternative to metal for better vibration control. Composites, known for their superior damping characteristics are more promising in vibration reduction compared to metals. The modeling of the blower was done by using solid modeling software, CATIA V5 R19. The blower is meshed with a three dimensional hex8 mesh is done using HYPERMESH 10. It is proposed to design a blower with composite material, analyze its strength and deformation using FEM software. In order to evaluate the effectiveness of composites and metal blower using FEA packaged (ANSYS). Modal analysis is performed on both Aluminum and composite blower to find out first 10 natural frequencies

M. Conclusion from paper:
– The stresses of composite blower obtained in static analysis 4.534 N/mm2 are within the allowable stress limits.
– The natural frequency of composite blower is reduced because of high stiffness and the lay-up sequence in the blower.
– The weight of the Composite blower is 15 kg which is less than the aluminum blower with a weight of 20 kg.
– From the results of harmonic analysis, damping effect is more in composite blower which controls the vibration levels.

III. CONCLUSION
From the above Literature Review and work and study done on the different non-structural components below are the generalised proposed Methodology and Procedure for Seismic Qualification of Nonstructural System:

For the Qualification of equipment following Requirements should be met,
– Structure Integrity and Pressure Boundary Integrity of Equipment
– Intended Functional Operability of Equipment

This can be performed By Analysis or by combination of analysis and test.

IV. QUALIFICATION FOR STRUCTURE INTEGRITY AND PRESSURE BOUNDARY INTEGRITY OF EQUIPMENT
Qualification of structure, systems and equipment whether passive or active can be performed by analysis to assess their intended functions in terms of structural integrity and pressure boundary integrity.

A. Qualification by analysis:
Qualification of structures, systems and equipment are required to be performed for various loads viz. load during design, normal and upset condition (pressure, temperature, mechanical cycle, transients); load during emergency and faulted condition (Pressure, Mechanical); test Load ; etc. The general Steps Involved as are below:
– Preparation of the Finite Element model Which Represent the equipment adequately. This can be done by selecting proper element for each component and proper meshing of assembly.
– Identification of applicable load type and its value.
– Perform static analysis on the assembly.
– Performing model analysis on assembly to find the natural frequency of the system. If first natural frequency of structure/element or assembly is above 33Hz (or rigid frequency) so analyze it by equivalent static method.
– perform dynamic(Harmonic) analysis on the assembly and determine the response for these loads in term of forces,moments,displacement and stresses.
– The Seismic response shall be determined by using response spectrum analysis/time history analysis/ equivalent static analysis method.
– Combination of seismic response with operating stresses and displacement for various load combination.
– comparison of combined stresses and displacement with those that compliance with design and codal analysis.

V. QUALIFICATION FOR INTENDED FUNCTIONAL OPERABILITY

Qualification of system can be demonstrated by analysis and/or testing for assessing their intended functional operability.

A. Functional Operability by analysis:
The seismic displacement as obtained by the analysis shall be combined with dis-placements/deflection due to other load shall be checked for operational/allowable clearances specified at various component, subassemblies, e.g. shaft bearing, impeller casing, stator-rotor, coupling alignment etc. The reactions coming at the bearing locations shall be less than bearing load capacity.

B. Qualification of Operability by Test :
Seismic test shall be carried out by mounting equipment on shake table. While seismic motion given to shake table, equipment shall be checked for intended function operability. During the test operating load/conditions of the equipment should also be simulated adequately. The test should be conservatively simulating the seismic event at the equipment mounting location. The multidirectional nature of earthquake should be simulated. This Test is depending on the size of component and shakes table limiting criteria. if size of component not match then only computer aided seismic analysis done.

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