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EARTHQUAKE WITHSTANDING TESTING AND CHECK ANALYSIS OF EQUIPMENT

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ABSTRACT

Growth of Industries and Power Plants(Nuclear, Thermal and Hydro) is on increase day by day world over. Most of these are located in seismic zones of considerable damage potential. In certain specific areas like nuclear power plants, petroleum facilities etc., consequences of failures are so serious that safety becomes an overriding consideration. Seismic qualification of equipment and structure for such vital facilities, in particular, has become mandatory demanding uninterrupted normal behaviour of equipment under postulated earthquake enviroment. For past few decades, research in Earthquake Engineering was centered around Civil engineering structures only with a little or no emphasis on equipment/machinery, Only very recently, attempts have been made to extend the domain covering equipment too. Although, the basic underlying principle. that the system (may be structure or equipment) should structurally remain integral or can sustain a pre-assessd damage during the postulated earthquake, is same both for structure and equipment, yet the criteria for seismic quali-qualification of equipment seems to be far different than those for structures. Further, whereas the analytical procedures used for seismic qualification of civil structures can be said to have been established and validated, such validation are practically missing so far as equipment are concerned. Equipment qualification can primarily be achieved by Lab Testing, Field Testing and Analysis. The present paper deals with seismic qualification requirements, method of qualification, eg. Testing/Analytical, their merits/demerits, limitations etc. and identifies the grey areas which need immediate attention.

Introduction

Earthquake engineering field for civil structure is still said to be in its infancy although work has been done for past 5 decades or so. On the contracy, the awareness for earthquake effects on plant and equipment has come very recently, say a decade and half back and it would not be out of place to say that there is a long way to go before one could develop the required level of confidence in establishing procedures, both analytical and experimental, leading to seismic qualification of equipment ensuring desired structural integrity without sacrificing functional and performance requirements.

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Unlike structures, earthquake withstand requirements of an equipment or a system of equipment depend upon large number of factors, which directly or indirectly influence and dictate the seismic qualification needs. Some of these are :

— Damage potential of an equipment
— Time for replacement/repair
— Spares inventory
— Capital investment
— Direct production losses due to plant shut down
— whether failure is hazardous
— Cost estimates of damage
— Extent of control protection devices provided in the system
— Post earthquake demand
— Cost of overdesign vs. gain in production etc.

Each of the above factor or their combination can dictate the extent of seismic qualification requirement. Hence in view of these factors, the different seismic qualification requirements could be laid down for different equipment at the same location in the plant and same equipment at different location in the plant, in accordance with their functional and performance requirements.

In Industry, some equipment may be fragile, some may need insolation for some, the supports may be highly non-linear even for slightest motion and for some, the level of excitation may be highly amplified by surrounding structure. These are some of the additional foctors which make the equipment response different than that of structure.

Although all the above factors make the equipment analysis difficult as compared to structure, yet there is one definite and clear advantage of equipment over structure, that the equipment can be more easily controlled during adverse conditions. On the other hand, for the facilities like major dams, nuclear power plant, petroleum facilities, etc., the consequences of uncontrolled failures are so serious that the safety becomes an overriding consideration.

Seismic Qualification of Equipment by Testing/Analysis

When we talk about earthquake withstanding testing of a structure, the inspection requirement during and after the test can be spelt out clearly with a fairly good level of confidence. However, in case of equipment it is not that easy to lay down such inspection requirements. Various questions which come to mind are :

- What are the test specifications and the basis of the same
- What kind of test is to be performed
- Can we meet the test specifications fully
- Whether prototype or model testing
- How to account for interface between adjoining equipment
- Whether testing under operating or non-operating conditions
- What parameters to be mointored during and after the test
- Post test observations and design modifications
- Whether existing codes are applicable to equipment
- Whether the required test facilities exist in the country
- What are the limitations of existing facilities
- Which of the test specifications can not be met with, in view of the limitations of test facility
- What are its implications on performance requirements
- How to brigde the gap
- What is the confidence level, and so on

With the availability of fast computers and the advancement in the computational techniques, it has become possible to model and analyse very large size problems. However, when one attempts to achieve qualification by analytical methods, one has to keep in mind the limitations such as :—

- For rotary equipment, it may not be possible to incorporate operating conditions.
- Qualification with regard to structural integrity could only be achieved
- Performance/Operational qualification is difficult to be achieved
- In some cases it may be difficult to model all the support conditions exactly.
- An equipment may comprise of different materials some of which may exhibit non-linear behaviour at very small input motion, some at very large input motion and some may remain elastic. At the outset it may be difficult to quantitatively establish these limits for the different materials. Even assuming that these limits are known,it may be difficult if not impossible to incorporate the same in the analysis.

Although there are limitations as described above, yet the analytical approach has a few distinct advantages over experimental one.

- It can accont for Interaction between equipment, support structure, foundation and soil wherever required.
- Interaction between group of eduipment connected through mechanical elements can be accounted for and necessary isolation measures could

be suggested if warranted.

- weak elements could be identified and adequate strengthening measures can be incorporated right at the design/manufacturing stage.
- Parametric variations can conveniently be done to achieve the desired response.

Hence it become clear that for some class of equipment neither test nor analytical method can provide the qualification needed, as dictated by the equipment. Thus a compromise has to be made keeping in view the following ;

- What is achievable
- How far it agrees with the specifications
- What shall be the implications on performance
- Whether the penalty to be paid is too heavy and so on

Hence with the available facilities both testing and analytical, and their limitations, seismic qualification today is more an art than science. However, the experience and confidence level play the predominant role in framing specifications/acceptance criteria.

EQUIPMENT QUALIFICATION

Broadly equipment can be classified inte (a) Static and (b) Rotary equipment both electrical and mechanical. For seismic qualification of an equipment, one needs to know the following:

- Equipment classification
- Seismic environment
- Specification
- Accpetance criteria
- Codal provisions
- Interaction with adjoining equipment
- Foundation/support interaction
- Various elements of the equipment, material of each and their properties
- Functional and performance needs and so on

Consider some equipment say Motor, TG, Condenser, Heaters, Transformers, Boiler etc for 200/210 MW power plant.Let us first consider static equipments like condenser and heater. Various element of these equipment are shell, tube-sheet, tube bundles, egg crates, nozzles etc. Besides, these have got either skirt support or bracket support with stiffners, anchor bolts, etc These equipments are either mounted on floors or supported on ground.

Seismic qualification of such an equipment broadly calls for following checks :

— Vibration of tubes, their interaction with the egg crates and their structural safety
— Vibration of tube bundle as a whole
— Stresses on nozzles due to connected piping
— Stresses in the shell, tube sheet and skirt/brackets
— Check on weld strength between skirt and the shell
— Adequacy of stiffner strength
— Stress on anchor bolts

Such a qualification can conveniently be achived through analysis with fairly good level of confidence as the analysis methods used are well validated.The qualification by testing can also be done subject to availability of shake table and handling facilities.

Let us take the equipment like motor. In power plant, motors (High voltage) are used in Turbine hall and boiler area. Motors for boiler feed pump, condensate extration pump, starting oil pump, circulating water pump etc are used in turbine hall. Primary air far motor, ID fan motors, FD fan motors, Bowl mill motor are used in Boiler area. All these motors are 6.6 KV with their ratings varying from 200 KW to 4000 KW, with speeds ranging from 500 rpm to 1500 rpm. The weight is as high as 20T. Some of these motors are horizontal and some are vertical. Bearings used are anti-friction bearings and sleeve bearings for horizontal motors and tilted pad type thrust and guide bearings and antifriction bearings for vertical motors. Bearing top clearances are 0 2 mm to 0.4 mm. Air gap between rotor and stator is of the order of 1 mm to 4 mm.

During earthquake, stampings can get shorted and create hot spots leading to failure. Stator windings can also get demaged. Change in Air gap can result in increased electro-magntic pull and may cause bearing failures. Rotor bars can get cracked. Besides the internals, damage can also be caused to bearing pedestals, base frame, anchor bolts, Foundation etc. In view of these and keeping in view the limitations of analytical approach, analysis alone can not provide the required seismic qualification for such a motor. This could best be achived through shake table tests provided such large shake table exists in the country and that too with required handling and operating facilities The question arises that in case the shake table facility is not there, how to go about with the qualification of such motors. The same is status for machines like compressors, turbines, generators, etc. One can think of carrying out the qualification studies in field by detonating charges. One may need to develop special sites for these purposes.

For most of the heavy duty machines, both analysis and test are needed. For example, for Turbo-Generator one can compute the amplification of acceration at the TG base frame through TG foundation and use that acceleration for shake table test as the foundation cannot be made on the shake table for testing TG. The cheek list after the test can contain the following:

— Check for journal bearing damage
— Check for thrust bearing damage
— Check for bearing pedestal
— Rubbing of blades to the casing/blade failure
— Rotor deformations
— Misalignment
— Nozzles/nozzle flanges
— Rotor/core winding of generator
— Base frame wilding/anchor bolts

In summary I would say that the field of seismic qualification of equipment is wide open and the work done is least. The appropriate shake table facilities in the country do not exist. In the National interest, it is a must to acquire and build up such required facilities at an early date otherwise the penalty paid would be too heavy if a major earthquake hits dense industrial area and cause damages to equipment. I am sure the society will not like to have this as a stimulus.