NUCLEAR PIPING DESIGN - AN OVERVIEW

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1.0 INTRODUCTION:

Nuclear piping design is a continuously evolving process. Advancements in analytical tools and the experience gained from the behaviour of structural systems under normal operating and extreme events like earthquake provide necessary inputs for refinement of design procedures/practices to achieve more economical and safe designs. Though last two decades have seen considerable improvements in analytical tools, still there appears to be an overemphasis on providing conservatism in seismic design resulting in non optimal designs (Ref. 1, 2, 3, 4). Present paper discusses aspects such as reliability and maintainability in the context of existing codal requirements of nuclear piping.

The uncertainty associated with magnitude of seismic events, their damage potential in combination with other operational piping loads and lack of reliable data during 1970's were contributing factors for building conservatism in the seismic design rules/procedures. However, present status of research and experience on performance of above ground piping systems indicate that the damage potential of seismic event has been considerably overestimated and that overstiff designs have been adopted which have drawbacks in satisfying flexibility criteria for normal operations.

The optimal design in the context of nuclear piping, therefore, should imply safe and trouble free operation throughout the life of plant with adequate margins provided for sustaining postulated seismic events. Though conformity with ASME code (Ref. 5) provides basic protection against piping failure, the issues related with reliability and maintainability, crucial for continued safe operation, can be best addressed through a rational design strategy. Such a design strategy should be based on careful evaluation of various loads vis-a-vis their damage potential and impact on overall safety margins.
2. NUCLEAR PIPING DESIGN - BASIC CONSIDERATIONS:

Nuclear piping design as per codal provisions is essentially an optimisation process. The major loads considered for designing piping are pressure, self weight, thermal expansions and seismic loads. Design for pressure and self weight are relatively easy tasks since they do not adversely affect the thermal expansion or seismic stresses. However, criteria for piping to accommodate thermal expansion and seismic stresses are mutually exclusive. A flexible piping is necessary to ensure that thermal expansions are absorbed within the piping network without overstressing whereas a stiff piping network is a precondition for low seismic stresses. Requirement for relatively stiff piping for seismic design stems from the fact that the peak of floor response spectrum, in general, extends from 3.0 - 8.0 Hz. In order to avoid such peak responses (like resonance) and subsequent overstressing of piping, the analyst stiffens the piping in such a way that fundamental piping frequency is higher than 8.0 Hz. However every additional support/restraint placed on the piping to increase its stiffness and frequency also increases the thermal expansion stresses. The analyst therefore iterates on addition/deletion of supports to optimise on flexibility as well as rigidity of piping network so as to qualify piping as per codal stress provisions.

Such an iterative process is expensive in terms of cost of analysis and project schedules. Additionally, any conservatism built into seismic design is reflected as stiffer piping which increases the operational thermal stresses. This in turn substantially reduces the stress margins which are required to cover stresses arising out of operational or other unforeseen reasons. This implies that owing to higher stresses, the probability of occurrence of failures due to the fatigue or corrosion fatigue or stress corrosion cracking, where stress plays a significant role, is increased. This has effect of reducing the reliability of designs. As a via media solution of retaining lower stresses and hence higher reliability, instead of providing rigid restraints, designers have incorporated snubbers in piping design. As many as 1000 snubbers per generating unit have been reportedly used on nuclear piping during 1980's (Ref.6). However experience on performance of snubbers is not so encouraging. Inadvertent locking of mechanical snubbers lead to high thermal expansion stresses whereas failure of oil seals in hydraulic snubbers makes snubber ineffective for seismic event. The safety concern associated with snubber failure and economic penalty of maintaining a large number of snubbers, has led the nuclear industry to undertake snubber reduction programs on the existing power plants (Ref.7).

3.0 CONSIDERATIONS FOR OPERATIONAL RELIABILITY AND MAINTAINABILITY:
Operational reliability of the piping will be essentially governed by low operating stresses, primarily, piping thermal expansion stresses. Low thermal stresses imply lower fatigue damage as well as lower support/equipment nozzle reactions. Simplicity of support configuration should be one of the prime objective towards achieving higher operational reliability. Simple unidirectional/bidirectional translational supports ensure that they are easy to fabricate and install, behave the same way as assumed in analysis, are maintenance free and help in reducing thermal gradients across the thickness due to better insulation efficiency. Welded attachments on the piping, which are not amenable to inspection due to overlapping insulation, should be best avoided. Such welded attachments are source of stress concentration and may lead to fatigue failure over a period due to thermal cycling. The degree of hazard associated with failure of welded attachment is more serious than the normal non-welded supports since it may directly lead to breach of pressure boundary.

Use of snubbers can best be minimised. It is suggested that design basis can also cover situations wherein certain mechanical snubbers are treated as locked (not all snubbers) if use of snubbers become unavoidable.

4.0 CONSIDERATIONS FOR RELIABILITY UNDER SEISMIC EVENTS:

Safety hazards associated with failure of class-1 nuclear piping makes it necessary to evaluate adequacy of piping under both operational as well as extreme load conditions. One major postulated load to be considered is seismic event. Reliability under seismic event should satisfy the conditions that;

-the piping is adequate to sustain the seismic load
-seismic design requirements are consistent with failure mode of piping under seismic event
-operational reliability is not compromised

Experience on performance of above ground piping in fossil power plants under seismic event suggest that the damage potential of seismic event has been grossly overestimated by nuclear industry (Ref.8). It also suggests that the ductile, seamless, buttwelded construction of nuclear piping, which is much more robust than the conventional power plant piping, should be able to withstand much higher earthquakes than it was thought to be. Research carried out on shake table testing of pressurised piping indicates that piping is able to withstand as high as 20-30 times the design basis SSE loading (Ref.1,9,10). The ASME code assumption that failure mode of piping corresponds to formation of plastic hinge and subsequent collapse of cross section due to inertial loads (considered as primary stress), is not supported by test results/experience. Instead, fatigue and ratchetting appears to be basic failure modes of piping under seismic event. Since this seismic design overconservatism
is at the expenses of reduction in operational safety margins, the need for reduction in seismic design conservatism becomes more evident.

The major parameters which lead to conservative seismic design are;

- Decoupled analysis of reactor building wherein dynamic feedback between building and internal equipment is normally neglected leading to higher floor accelerations.
- Peak broadening of floor response spectrum which increases the energy content of earthquake to be resisted by piping.
- Conservative damping values for piping analysis.
- Envelope response spectrum approach for piping supported from differential floors/elevations.
- Overestimation of damage potential of seismic loads.
- Coupling of OBE with SSE and dual damping for OBE and SSE resulting in OBE being a governing design seismic event.

Approaches to reduce the seismic conservatism can be grouped into two options namely;

- those which lead to reduction in estimation of seismic loads (like increase in damping, peak shifting of response spectrum, multiple support response spectrum analysis) and

- those which permit higher allowable stresses to counter effect of seismic conservatism (like consideration of seismic stresses as secondary stresses or allowing higher allowable stresses under seismic event).

It is felt that the first option is more promising. This is because equipment nozzle loads are also a part of piping designer's responsibility and hence reduction in seismic forces will help in not only evolving the reliable piping design but also meet the requirement of equipment vendors. Therefore use of damping recommended by PVRC and use of multiple support response spectrum analysis are the two major design procedural changes which will result in satisfying both operational as well as seismic considerations and provide adequate reliability.

It is suggested that failure of some of the hydraulic snubbers should also be considered in the piping design.

Experience indicate that seismic anchor movement (SAM) related stresses, which are deformation controlled and hence secondary in nature, have been contributing factors towards the failure of piping/supports. Though OBE SAM stresses are explicitly covered in service levels "B", there is no provision for SSE SAM stresses in level "C" and "D" of ASME code. However, in view of damage potential associated with SAM loads, it is suggested that SSE SAM loads be explicitly considered, at lest for support design, in service level "C" and "D".
5.0 SUPPORT DESIGN CONSIDERATIONS:

The functional reliability of piping under both operational and seismic events can be qualitatively correlated to the fact that piping is an indeterminate structure with numerous intermediate supports and hence failure of a minimum number of supports is essential for piping to collapse or lose its functionality. It is equally worthwhile to note that failure of ductile, butt-welded robust piping is mainly due to excessive strains rather than temporary cyclic high stresses as in case of a seismic event. Failure of supports, however, may lead to such high strains and hence increased reliability of support design should be an essential element of piping design strategy. For example provision of two relatively smaller supports instead of one single heavy support may be examined in order to achieve redundancy implying improved reliability.

The aspect of providing support gaps in excess of current practice of 0.125" (Ref.1) needs closer evaluation. It may be noted that the thermal expansion stresses are function of relatively smaller restrained displacements and hence can be substantially reduced if larger then 0.125" gaps are provided. Additionally it will also reduce the support loads which can be substantial, particularly for large diameter piping. Higher gaps cause lower stresses/support loads and hence add to the reliability of piping system. The effect of larger support gaps under seismic event is however two folds. The impacting between the support and piping may lead to higher localised piping stresses while on the other hand these gaps will help in reducing seismic anchor movement induced stresses for multiply supported piping and in reducing overall piping loads due to higher dry friction damping associated with the larger gaps. The advantage gained in operational reliability, reduced SAM stresses and increased damping may at best be offset by the higher localised stresses due to impacting. Additionally such offsetting effect is only for a short duration and should not be a governing factor while deciding about support gaps.

A residual mass correction (Ref.11) is recommended to realistically assess support loads as conventional response spectrum analysis has limitation in not considering contribution from mass elements close to supports.

6.0 CONCLUSION:

From the foregoing discussions, the following broad recommendations can be derived which when implemented in design procedures are expected to result in a more optimal and reliable design of nuclear piping;

- Minimisation of use of snubbers on piping.
- Contemplating snubber failure as one of design basis if
snubbers could not be avoided completely.

- Realistic/conservative estimation of support loads for both operational and seismic events.
- Use of simple gapped supports and avoiding welded attachments.
- Redundancy in number of supports.
- Use of PVRC damping and multiple support response spectrum analysis.
- Use of simplified elastoplastic analysis of ASME code (if required) for accommodating higher seismic loads which will permit lower operational thermal stresses.
- Consideration of SSE SAM loads for support design.

The design and analysis procedures of ASME code and regulatory standards may perhaps consider the above aspects to integrate reliability and maintainability aspects in the piping design practice to achieve more optimal designs.

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8.0 REFERENCES: