Minimizing Seismic Restraints and Eliminating Snubbers from the Piping Systems of New CANDU Nuclear Reactors

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ABSTRACT

Using present day concepts, extensive design optimization and latest ASME Code changes, AECL CANDU is successful in reducing the number of dedicated seismic restraints and in eliminating snubbers from currently designed CANDU plants. Detailed design instructions enforce sound design practices to a large team of piping designers and analysts.

1 INTRODUCTION

AECL CANDU is presently designing the CANDU 3 reactor, which is the latest and the smallest version of the CANDU line of Pressurized Heavy Water Reactor (PHWR) systems developed in Canada. While using proven systems, concepts and components throughout, the CANDU 3 incorporates the latest available technologies in all areas, ranging from design and construction methods to plant control systems.

With an output of 450 MW(e), the CANDU 3 provides a highly flexible plant configuration which is readily adaptable to a wide range of different user requirements and sites. In all design aspects, specific attention is paid to: minimization of capital costs; the provision for a short and manageable construction schedule; the assurance of high capacity operation; and, the maximization of component life and the provision for fast and easy replacement of components.

In designing the CANDU 3 piping systems, AECL CANDU piping engineers are faced with two major challenges. The first challenge is to use modern design concepts and approaches in order to increase the safety and reduce the cost of piping systems now being designed, and do this while the rules and regulations that govern the design process have just started to adapt but have not yet caught up with these new concepts and approaches. The second challenge is to enforce sound design practices to a large team of piping designers and analysts.

The next sections describe the methodology adopted by AECL CANDU in the design of seismically qualified piping systems, to meet these challenges.

2 NEW CONCEPTS, OLD RULES

Safety related piping systems in nuclear power plants are currently designed and evaluated for seismic loads using sophisticated analytical procedures.
These procedures and the conservative assumptions that accompany their use have led to large expenditures of engineering and construction manpower, to high initial and maintenance costs, to increased radiation exposure of maintenance personnel, and to safety concerns related to the adverse effects of thermal loads in highly restrained piping systems.

 Aimed at improved design methods, extensive research programs have been conducted in the last decade in many countries, while experience data was collected on the performance of piping systems in actual earthquakes. These activities have resulted in an improved understanding of piping system behaviour under seismic loading conditions; following concepts are now generally accepted:

 - piping does not collapse under seismic inertia loading alone
 - failure connected with the seismic event is usually due to the restriction of seismic anchor movements, interactions and local weakness
 - there are very large seismic safety margins between the present design conditions based on linear-elastic analysis and the ultimate limit
 - gaps and other non-linearities tend to increase system damping in a very significant way, especially at high dynamic strain levels
 - stiff systems tend to be less safe because they are associated with higher fatigue factors and plant congestion
 - the traditional methods of seismic analysis often lack accuracy due to limitations of the linear analysis methods and to modelling deficiencies
 - snubbers pose a safety hazard and represent an important economical burden for any operating nuclear power plant.

 Regulatory bodies have launched an effort to update the rules and regulations presently governing the design of piping systems and base them on more realistic criteria (Guzy 1988). Important progress has already been made. According to several reports (Aggarwal et al. 1988; Quadrex 1986; Sall and Bostrom 1990), introduction of RCM Code case N-411 alone has allowed the elimination of a high proportion of the snubbers installed in currently operating plants. Work on many more regulatory changes is in progress, the seismic design philosophy itself is now under review. It will take however a few years before present day knowledge will consistently be incorporated into governing design codes; therefore, an organization designing a new nuclear plant to-day, has to satisfy Code requirements that limit its ability to implement optimum solutions that reflect modern concepts.

 It is in this regulatory environment, characterized by modern concepts and older rules, that AECL CANDU engineers had to devise the CANDU 3 design strategy.

3 THE CANDU 3 DESIGN APPROACH

3.1 Design criteria and design guidelines

One of the key objectives in the CANDU 3 design is to use proven systems and concepts while incorporating latest available technology in all areas of design and construction; the CANDU quality program requires engineers to study the design concepts and criteria during the preliminary engineering phase and translate them into design requirements to be used as input to the detailed design and engineering work.

The CANDU 3 design criteria for seismically qualified piping systems ensure that above objectives as well as the applicable regulatory requirements are consistently satisfied:

 - low thermal stresses (maximum 2/3 of allowable values in the final arrangement)
 - very low gravity stresses (15 to 20 MPa)
- seismic stresses close to, but within, allowable limits
- seismic displacements clearly defined and limited to allowable values
- supports generously sized to resist conservatively calculated loads
  from all postulated events; actual support flexibility accounted for
- supports designed for multi-purpose functions (gravity, seismic, water
  hammer, pipe whip, etc.)
- protection against elastic follow-up (weaker components damaged by the
  displacement of stronger parts of the system) and interaction
- the potential for water hammer, vibration, thermal stratification,
  corrosion, erosion clearly defined and protective measures taken in the
  early design phase
- no use of snubbers
- limited use of non-linear restraints.

To meet these criteria, the piping engineer is instructed to engage in a
thorough design optimization process, based largely on conventional design
practices; only when it becomes evident that the conventional methods of de-
sign and analysis would negatively impact a system’s operational safety,
are alternative hardware and analysis methods implemented. The AECL CANU
"Pipe design and stress analysis design guide" was revised and expanded to
include detailed instructions based on above requirements. These are pre-
sent ed here in a condensed format:

(a) Start with an isometric of the unrestrained piping system and add
the mandatory anchors (equipment nozzles, penetrations, etc.); show the
areas of the piping system where restraints can not be installed (too far
away from supporting structures, overcrowding, etc.).
(b) Perform a thermal analysis; optimize the layout for thermal
stresses. Provide additional flexibility, if necessary; eliminate un nec-
essary loops; thermal stresses should ideally be kept as low as 85 to 110
MPa; show the areas of small thermal movement on the stress isometric.
(c) Place gravity supports and perform a dead weight analysis; the gravity
supports should not significantly increase thermal stresses (use springs
as necessary).
(d) Perform a first seismic analysis (based on a few modes only). Avoid
over conservatism. If the seismic stresses seem low or marginal (125 MPa
or lower) perform the complete stress analysis including the Code evalua-
tion. If the Code evaluation fails, continue with (e) below.
(e) If the seismic stresses and/or displacements are excessive, start
restraining the sections of large seismic movement by placing rigid re-
straints in locations of small thermal movement; consider changes in pipe
routing and the use of engineered restraints; optimize the restraint ar-
range ment to obtain low gravity and thermal stresses and seismic stresses
within allowable limits; if successful, complete the stress analysis, in-
cluding Code evaluation; if the optimization process did finally not re-
sult in compliance with Code requirements, i.e. rigid restraints can not
be used in all locations, continue with (f) below.
(f) Replace the problem rigid restraints with non-linear restraints (not
snubbers) and perform the stress analysis ignoring the effects that make
the system response non-linear (for example the gap effects). Final qual-
ification will be performed later, as discussed in Section 4.

The engineered restraints mentioned at (e) above refer to a variety of lin-
ear restraining arrangements, such as gapped restraints locked in hot posi-
tion, thermally self adjusting struts, non-orthogonal struts, linear energy
absorbing supports, etc. Piping systems using these types of engineered re-
straints can be analyzed using conventional methods.
3.2 The CANDU 3 Heat Transport (HT) System

The example of the CANDU 3 Heat Transport (HT) system (Figures 1, 2, and 3), which is the equivalent of a PWR Reactor Coolant System, is used here to illustrate how sound design practices implemented in the early stages of design have resulted in a flexible HT arrangement, with very few (sturdy and simple) supports and with no snubbers. Only the large bore HT piping, the inlet/outlet headers and the main steam lines are discussed here.

A total of four restraints are used for all HT lines and another six restraints are used for the headers; none of these restraints are snubbers; each of the Main Steam Lines needed only one pipe whip and two seismic restraints. This is an unusually small number of restraints, taking into account that the CANDU 3 reactor is designed for high seismic loading (which envelopes the requirements from most potential sites, worldwide), that some HT lines are very long (one pump suction line is over 30 m long), and that protection against all postulated loading conditions (including pipe whip) is provided.

This advantageous arrangement of the HT system was made possible by extensive design optimization and by the use of a variety of sophisticated restraints, including engineered linear restraints (the header supports are locked in hot position) and multi-purpose restraints (one of the HT restraints acts as a combined gravitational, seismic, water hammer and pipe whip restraint); two gapped restraints (one for each pump suction line) had to be used. The HT lines run close to the reactor building internal concrete structure, which was sized to withstand all static and (conservatively estimated) dynamic loads.

4 Qualification of Piping Systems with Non-Linear Restraints

The CANDU 3 design instructions call for the limited use of non-linear restraints. The preferred type of non-linear restraint is the gapped restraint (Seismic Stop) because it is simple and passive; other types of non-linear restraints (such as the supports designed to dissipate energy by yielding) may also be used as warranted by a particular situation.

The decision to limit the use of non-linear restraints is connected with analysis difficulties. Once a non-linear restraint is used on a piping system, that system becomes itself non-linear and can no longer be analyzed using the response spectrum method. The remaining alternative, using the time history analysis method, is not a desirable solution for routine analyses of piping systems because time histories for all support attachment points are not readily available in the early stages of design (when the major piping systems must be analyzed); and also because the time history method is very labour intensive.

The decision to use gapped restraints on CANDU 3 piping systems, is based on the results of extensive verification programs by test and analysis (Rot et al. 1980; Yang et al. 1988; Steinheiler et al. 1989; Yang et al. 1989; Leung et al. 1989). Solid evidence is now available that non-linear restraints behave in a predictable way and are capable to withstand simulated seismic events (often by many orders of magnitude stronger than the most severe earthquakes over recorded) at least as well as the systems using conventional restraints.

Two alternative approaches are presently investigated at AECL CANDU to analyze piping systems with non-linear restraints:

(1) Applying an equivalent linearization method (at least one commercial code is available that implements this technique and development work is also conducted in-house); the equivalent linearization method has been,
in principle, accepted by the US NRC.  
(2) Using a load amplification method: a parametric study, funded by the  
CANDU Owner's Group, is now under way and was set up to determine an  
applicable range of envelope dynamic load amplification factors (as a  
function of piping system parameters and gap size) to be applied to the  
results from conventional seismic analyses.  
Both approaches are pursued and an acceptable method for the analysis of  
piping systems with gapped restraints should be in place within the next 12  
months.  
The risk associated with the use of devices which call for analysis meth-  
ods that are not yet widely accepted is considered minor, while the exclu-  
sive application of conventional methods would lead to the use of snubbers  
and consequently, to more expensive and less safe piping systems. As a last  
resort, the time history analysis could be used to demonstrate Code com-  
pliance for a specific system in the later stages of the project, when  
applicable time histories will have become available.

6 CONCLUSIONS

The CANDU 3 design is aimed at snuberless, flexible piping systems and is  
implemented by using detailed design instructions to promote system opti-  
mization and by making limited use of non-linear restraints. Development work  
presently in course will result in a suitable method for the qualification  
of non-linear, seismically qualified piping systems.

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