# COMPONET SPECIFIC RESPONSE SPECTRUM FOR BRUCE B

**Manu Puliyaneth**[1]

[1] Engineering Trainee, Bruce Power, Tiverton, Ontario, Canada (manu.puliyaneth@brucepower.com)

## ABSTRACT

Many of the historically installed valves (valve-actuator assembly) must be replaced. Generally, the replacement valves are much heavier or differ in their orientations – potentially having a different seismic response and integrity. Valves are seismically qualified by the manufacturer using the Floor Response Spectra (FRS) pertaining to the valve location as an input, however they may be overly conservative requiring the generation of Component Specific Response Spectrum (CSRS). A site/component-specific analysis was performed using Ansys to generate the CSRS for four (4) valves at Bruce B. This paper discusses the methodology adopted and the estimation of the CSRS for the valves.

With the buildings acceleration-time history provided as inputs at the supports, generation of the valve specific CSRS follows a two-step process: Step 1 includes generation of the acceleration time history at the valve location using Ansys Workbench. Step 2 involves converting the extracted acceleration time histories to response spectra (acceleration – frequency) with a simple beam model using Ansys APDL.

## INTRODUCTION

Nuclear power accounts for over 50% of Ontario's total generated electricity as per (Wilde, Nickerson and Deleon (2018)). Considering the global drive for sustainable and low-carbon emission energy source, it is reasonable to expect that the dependence on nuclear power for electricity generation will increase in future. The radioactive nature of the fuel mandates stringent requirements to ensure the structural integrity of piping and piping components – including valves in the Nuclear Power Plant (NPP), during normal operation and any potential seismic event. Maintaining the integrity of piping and piping components during a seismic event is of paramount importance as any damage to them may lead to undesirable scenarios that can impair the safety of the nuclear power plant, lead to possible radiation leakage or internal flooding resulting in multi-hazard accidents (Kwag, et al. (2022)). Recognising the ability of a seismic event to cause such damages, qualifying valves against seismic loads are a standard practice within NPPs (Han, et al. (2014)). Apart from the structural integrity perspective, piping components shall meet pressure boundary requirements also.

Within Bruce Power (BP), many of the historically installed valves are being replaced. Due to various reasons, the new valves differ in weight, orientation and centre of gravity – aspects that impact the seismic response - compared to their predecessors. Seismic qualification of valves is quite a complex process, for instance, the ground motion leads to floor vibrations, this in turn is absorbed by the pipes on which the valves are mounted. The pipes in turn can propagate this shaking with or without amplification on valves connected to them (Dar, McKinnon and Konstantinidis (2012)). CSA N289 series discusses in general about the seismic requirements and qualifications pertaining to NPPs within Canada. Specifically, CSA N289.4 discusses about the various testing processes, requirements and methods that may be used to seismically qualify nuclear power plant structures, systems, and components. Shake tables test is a procedure used to seismically qualify components. They can simulate earthquake motions in a lab environment. By subjecting components to shake table testing, it is possible to assess if they can withstand an earthquake (corresponding to the input spectra considered in the shake table test). BP has specifications developed based on CSA standards that provides guidance on the Required Response Spectrum (RRS) to be used for shake table tests. However, they lean towards the conservative spectra calling for the generation of CSRS in extreme cases to aid in shake table tests. (Hur and Nam (2007)) discusses the effect of increased seismic loads on Advanced Power Reactor 1400 (APR1400) in-line components and provides suggestions for acceleration values for their qualification.

The objective of this paper is to generate CSRS for a set of four motorised valve-actuator assembly, for use as input in shake table tests. Functions of Motorised Valves, include shutting down during a seismic event and maintaining the safe shutdown condition (Matsubara, et al. (2020)), highlight their importance in an NPP.

## EVALUATION PROCEDURE

The methodology adopted within this study for the generation of CSRS can be described in two steps. The general approach is as detailed below:

<u>Step 1</u> - The acceleration time history, specific to the building structure and the piping system elevation, are imposed as input loads on the piping model. This is applied at locations where the pipes are embedded into the building structure. This step concludes with the acceleration time history output being extracted from each of the valve locations.

<u>Step 2</u> – The acceleration time history output extracted in the previous step is converted to response spectra (acceleration – frequency) with a simple beam model using Ansys APDL.

## ANALYSIS AND RESULTS

### *FE Modelling for Step 1*

Figure 1 presents the routing of the pipe, the location and orientation of the four (4) motorised valve-actuator assemblies, and locations where the piping penetrates (is embedded) the building structure. The valve-actuator assemblies are designated - V1, V2, V3 and V4, and will be referenced as such for discussions within this paper. The valves are butterfly type valves connected to the piping system via flanges. The piping penetrates (is embedded) the building structure are three locations. V1, V3 and V4 are relatively closed to the building penetrations. However, V2 is on a U-loop with no additional supports, a configuration resembling a cantilever. V1 and V2 have extensions on top of the valve, on which the actuators are placed. V3 and V4 have their actuators on the valve bracket. Material properties considered for the analysis are indicated in Table 1.

Table 1 Material properties for pipe, valve and support plates.

| Component | Material | Elastic Modulus (psi) | Density (lb/in$^3$) |
|---|---|---|---|
| Pipes/Flange | SA 106 Gr B/SA 234 Gr WPB | 27.9 x $10^6$ | 0.284 |
| Valve body | SA 216 Gr WCB | | |
| Bracket/Extension | ASTM A36 | | |

The piping components (pipe/elbows/flanges) are modelled using shell elements with the appropriate offset definition to account for the thickness. The valves are modelled using solid elements. Mesh sensitivity was done by varying the mesh sizes in the piping section. The model has a total of

86,107 element. A Hex dominant meshing method is used within the analysis. The shell elements uses linear element type and the solid elements use quadratic formulation/element type. For modelling simplicity, no bolts or nuts are modelled. All bolted joints are modelled as bonded contacts. All pipe to flange connections are also modelled as bonded joints. The actuators are modelled as lump mass (200 lbs) at their centre of gravity with a rigid connection to the top surface of the valve extension (V1 and V2) and valve bracket (V3 and V4).

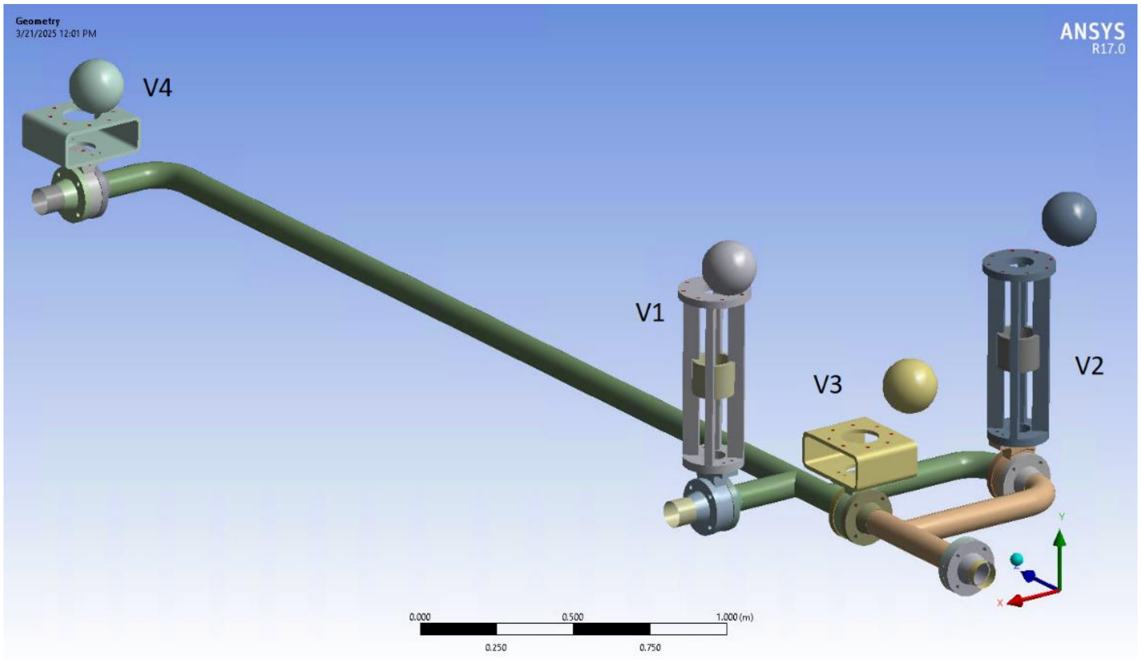


Figure 1. Overall Geometry with boundary conditions.

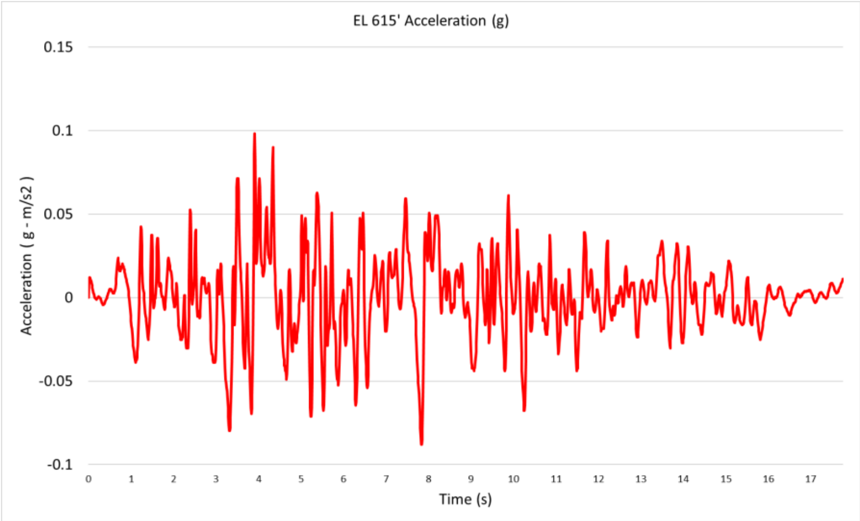


Figure 2. Applied Acceleration Time History at the fixed boundaries.

Fixed boundary conditions are imposed at the pipe ends where they are embedded into the building structure. The input acceleration loads are applied to the model through these fixed boundaries. The applied input acceleration time history loads are indicated in Figure 2. They are the same for North-South (NS), East-West (EW) and Vertical directions.

A transient analysis is run using modal superposition method and using a constant damping ratio of 5%. Prior to initiating the transient run, the model is pre-stressed by applying the acceleration due to gravity, further a modal analysis is also undertaken. The input acceleration time history has a time increment of 0.01 seconds. A constant time step of 0.001 seconds is used for the analysis – which is 1/10th the size of the input. A sensitivity study was run using time steps of 0.01 also and the results indicated no/minimal influence.

***Results for Step 1***

Four nodes on the valve surface (bonded to the flange) near the bolt holes were selected to generate the acceleration time history. Across each of the nodes for a valve, the change in the acceleration time history output variations is minimal. The acceleration time history from one of the nodes from each valve-actuator assembly is presented in Figure 3

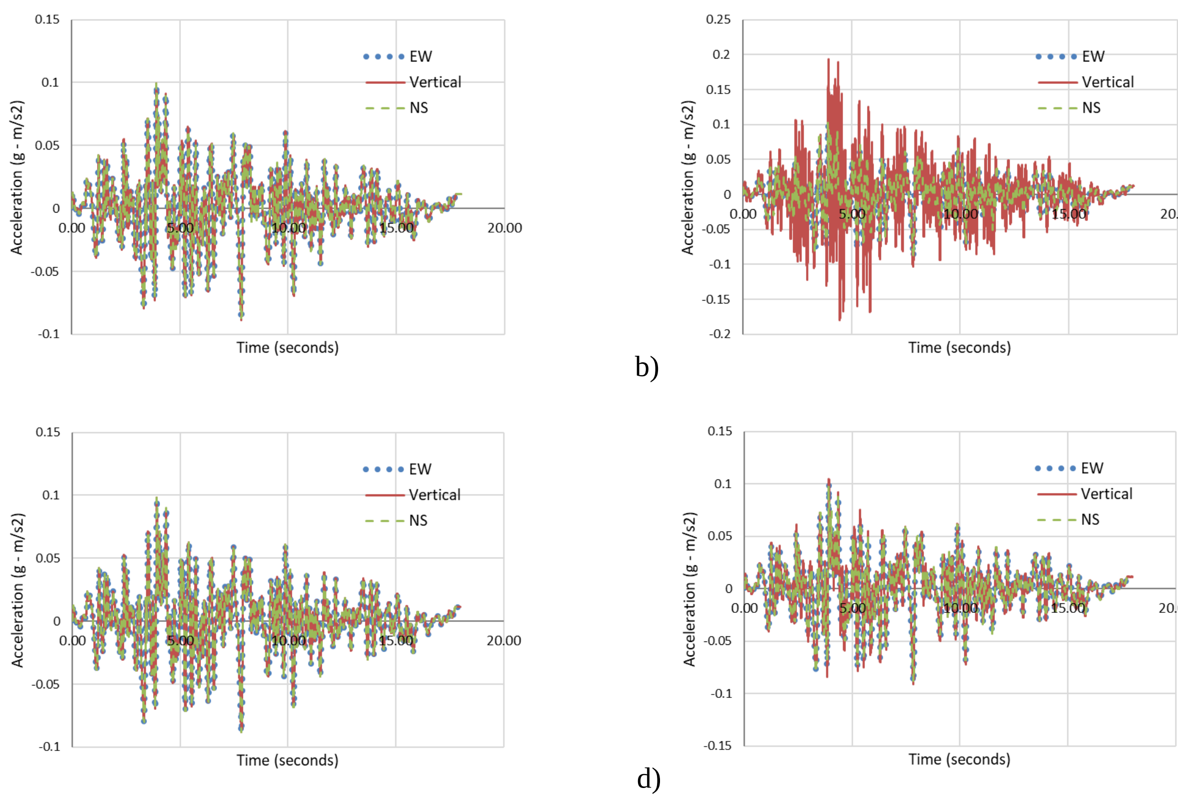


Figure 3. Acceleration time history for valves a) V1; b) V2; c) V3; d) V4

V1, V3 and V4 have their responses similar and comparable to the input acceleration time history. This can be attributed to the valve assemblies being positioned close to the building penetrations and hence there is no amplification of the input acceleration. However, for V2 the output acceleration is different in the vertical direction with a peak at around 0.2 g. This can be attributed to the cantilever resembling configuration of the U-loop on which it is placed.

### *FE Modelling for Step 2*

Ansys APDL can be used to generate the response spectra for a given acceleration time-history input using the RESP command. For this a simple rigid solid cylinder – 1’ diameter x 1’ height is modelled using beam elements. A fixed boundary condition is imposed on node 1. The mechanical properties indicated in Table 1 are assigned for the cylinder. The acceleration time history output obtained in Step 1 is input at node 1 and the CSRS is extracted from node 2.

### *Results for Step 2*

The response spectra generated from one of the nodes from each valve-actuator assembly is presented in Figure 4. The peak acceleration for V1, V3 and V4 in all directions are observed to be between 2 to 8 Hz. For V2, there is a sharp peak to around 1.25 g at 7.5 Hz in the vertical direction, this is in line with the peak observed in the acceleration time history presented earlier.

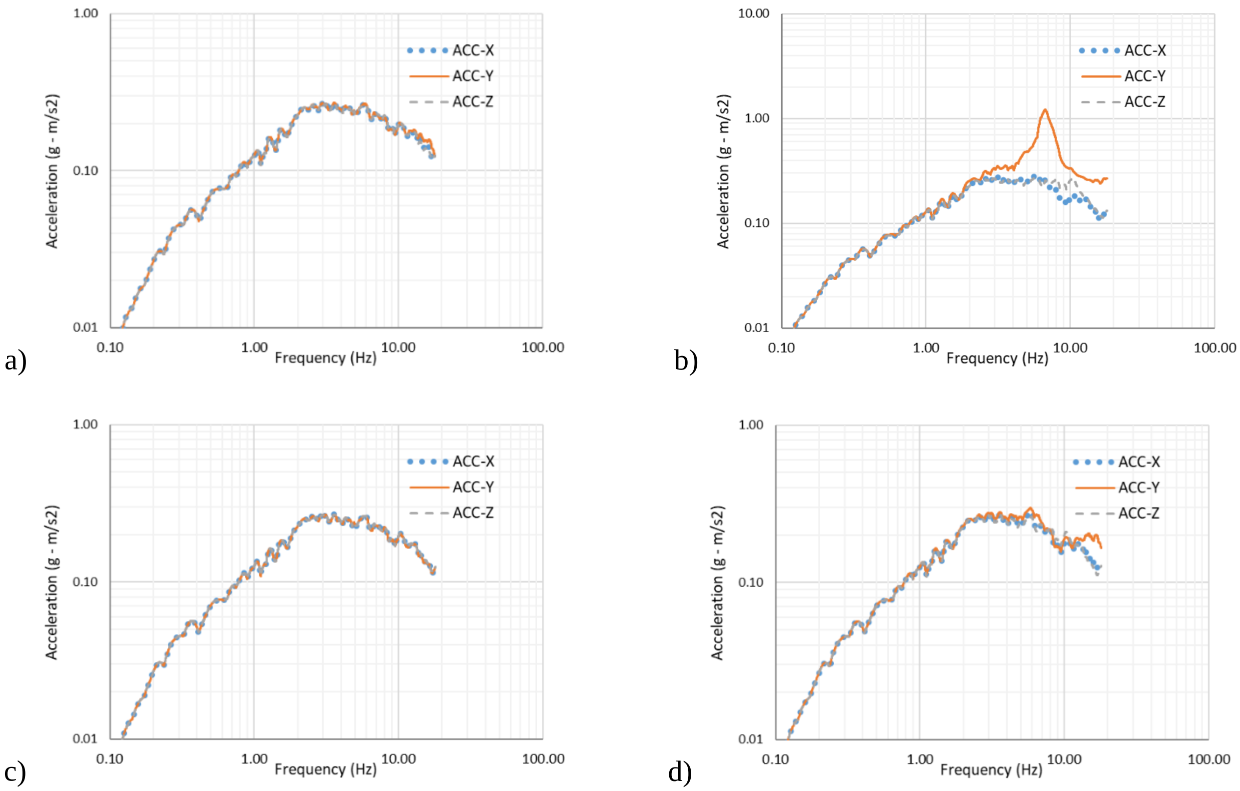


Figure 4. Response Spectra (Frequency-Acceleration) for valves a) V1; b) V2; c) V3; d) V4

***Bounding response spectra***

The response spectra generated in Step 2 are bounded to create a single set of response spectra for all the four valve-actuator assembly. A single set of data is generated for NS and EW directions; and another set is generated for the vertical direction.

The response spectra (frequency-acceleration) extracted from Step 2 is initially plotted. Maintaining the acceleration, the frequency is shifted by + and - 15%. This yields a set of 3 response spectra. They are plotted and a set of straight-line segments are determined to generate the bounding response spectra. The bounding response spectra are presented in Figure 5 and Figure 6, for the lateral (NS and EW) and vertical directions respectively.

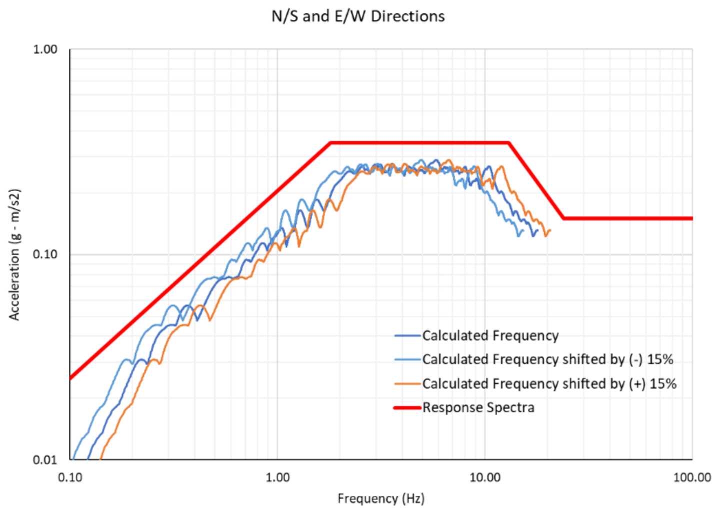


Figure 5. Bounding response spectra – Lateral direction

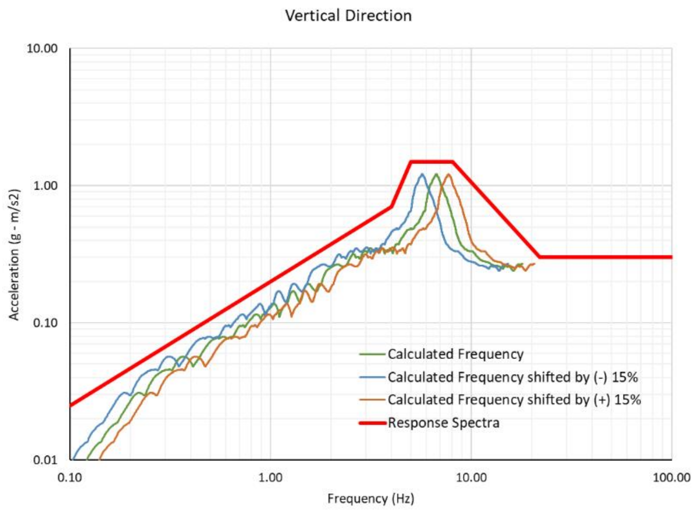


Figure 6. Bounding response spectra – Vertical direction

## CONCLUSION

A site/location specific CSRS for four (4) motorised valve-actuator assembly at Bruce B are calculated and presented within this paper. A bounding spectrum is also developed taking into consideration all the individual response spectra generated. This may be used within shake table tests to assess the seismic acceptability of the valve-motor assembly.

Results from the bounding spectra indicate a maximum acceleration of 1.5 g in the vertical direction, peaking between 5-8 Hz; and 0.35 g in the lateral directions, peaking between 1.8 to 13 Hz.

## ACKNOWLEDGEMENTS

The author gratefully acknowledges the support from Bruce Power during the course of this work and expresses his sincere thanks. Thanks are due to Amitabh Dar, Technical Advisor (Bruce Power) for his technical support in completion of this work. Last but not the least; the author is thankful to Daniel Bajwa (Kinectrics) for providing the geometry files of the piping system.

## REFERENCES

Dar, Amitabh, Brian McKinnon, and Dimitrios Konstantinidis. (2012). "Seismic Qualification of Structures, Systems and Components in a Canadian Nuclear Power Plant." *3rd International Structural Specialty Conference.*

Han, Sang-Uk , Dae-Gyun Ahn, Myeong-Gon Lee, Kwon-Hee Lee, and Seung-Ho Han. (2014). "Structural Safety Analysis Based on Seismic Service Conditions for Butterfly Valves in a Nuclear Power Plant." *The Scientific World Journal.*

Hur, Seok Hwan, and Il Kwun Nam. (2007). "Evaluation Of Seismic Qualification Requirements For In-Line Components (Active Valves) Following The Seismic Design Load Change." *15th International Conference on Nuclear Engineering, Nagoya, Japan*, April 22-26.

Kwag, Shinyoung, Seunghyun Eem, Jinsung Kwak, Hwanho Lee, Jinho Oh, Gyeong-Hoi Koo, Sungjin Chang, and Bubgyu Jeon. (2022). "Shaking table test and numerical analysis of nuclear piping under low and high frequency earthquake motions." *Nuclear Engineering and Technology* 54 (9): 3361-3379.

Matsubara, Yoshinao, Koji Nishino, Nobuo Kojima, Yoshitaka Tsutsumi, Shin Kumagai, and Hiroyuki Kamino. (2020). "Seismic Test Results Of The Especial Valves And Valve Actuators For Nuclear Power Plant." Sendai, Japan: The 17th World Conference on Earthquake Engineering.

Wilde, Cassandra , Kinsey Nickerson, and Josephine Deleon. (2018). *Nuclear Energy in Canada Energy Market Assessment.* National Energy Board.