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Seismic Response Evaluation of the Control Element Drive Mechanism with a Lateral Seismic Support

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1. Introduction

A Control Element Drive Mechanism (CEDM) of a pressurized water reactor is an electromechanical device to position the Control Element Assembly (CEA) in the core. The CEDM is vertically mounted on the reactor vessel head like a cantilever so that it is vulnerable to lateral deflection under earthquake excitation. Major safety functions of the CEDM are to sustain the pressure boundary and enable the CEA to fully drop in the core within the acceptable time during earthquake excitation. In order to enhance the seismic capability, the design concept of a seismic support is under investigation to restrain the motion of the CEDM. The implementation of the seismic support surely causes the changes of the seismic responses of the CEDM.

This paper presents seismic loads and deformation of the CEDM with respect to the seismic support heights. The changes of the CEDM loads are compared with the loads for free standing CEDM. The acceptance of CEA scram is evaluated for each supporting height as the CEDM's deflection is changed depending on the supporting height. Based on the changes of the seismic responses, desirable installation heights of the seismic support are recommended.

2. Methods and Results

2.1 CEDM Design and Analysis Methods

There are seventy three (73) CEDMs on the reactor vessel head for operating OPR1000 plants. The CEDM consists of four basic components, nozzle, motor housing (MH), upper pressure housing (UPH), and upper shroud. The nozzle, motor housing and upper pressure housing sustain the pressure boundary for the reactor coolant as a safety function. Other safety function is to release the extension shaft assembly with CEA to drop for rapid insertion in the fuel assembly within the acceptable time. Those safety functions should be accomplished in any accidental conditions.

It is expected that the seismic support for the CEDM causes the changes of the seismic responses of the CEDM. Under this condition, the structural integrity of the CEDM pressure boundary should be maintained and the deformation should be evaluated for the CEA drop time requirements, so called as scram criteria.

In order to calculate seismic responses, three CEDMs with the shortest, middle and longest nozzle length are included in the analysis model because their responses can represent results for all CEDMs. Considering the design constraints around CEDM structure, it is also assumed that the seismic support can be located from the CEDM top to 6.5 feet below. The parametric analyses are carried out by changing the support height in the range. The seismic support is simply modeled as a boundary condition constraining the displacements in horizontal direction. The movements in vertical direction are allowed because of free thermal growth. For the seismic excitation, enveloping response spectra at the reactor vessel head for OPR1000 plants used for the analysis. The analysis is performed by using the conventional computational program, ANSYS [1].

2.2 Modal Responses and Seismic Loads

For free standing CEDMs, the first and the second mode frequencies occur at around 3 Hz and 14 Hz, respectively. However, the supported CEDM does not have the similar first mode with the free standing CEDM due to the support. The first mode shape for supported CEDMs corresponds to the second mode shape of the free standing CEDMs. The varieties of the first mode frequency for CEDMs with various support heights are shown in Fig. 1.

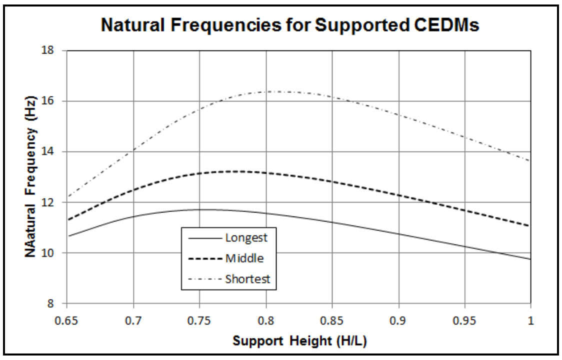

Fig. 1 Natural Frequencies for Supported CEDMs

It is observed that the CEDM with the longest nozzle shows much lower frequencies than those of other CEDMs. The highest frequencies exists where the support is located in height of about 0.75~0.80 of H/L (Support height/Total CEDM length). It means that the CEDMs are much stiffened when the support is positioned in these heights. The tendency of the frequencies is closely matched to the natural frequency parameter for the two-span beam presented by R.D Blevins [2]

The seismic loads for CEDM pressure boundary components of nozzle, motor housing and upper pressure housing are presented in Figs. 2 and 3, shear forces and bending moments, respectively. In the analysis the heights for supporting CEDM are varied from 0.65 to 1.0 of H/L. The result loads for supported CEDMs are normalized to those for the free standing CEDM.

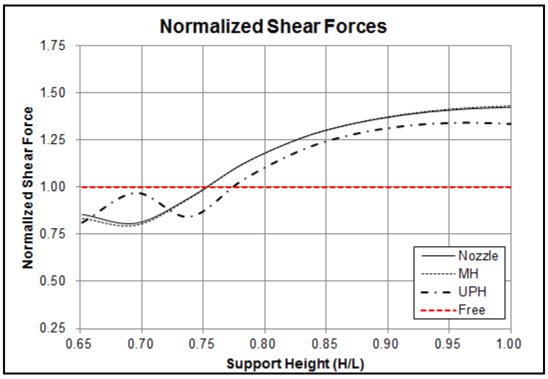

Fig. 2 Normalized Shear Forces

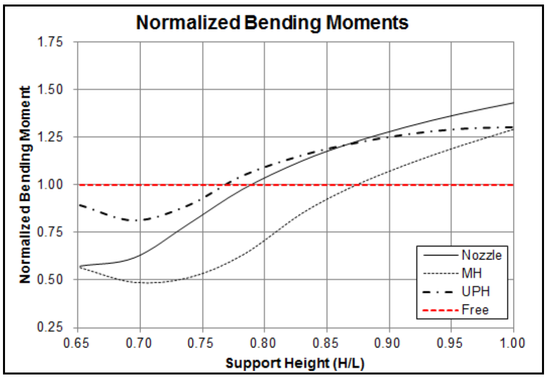

Fig. 3 Normalized Bending Moments

Both shear forces and bending moments show maximum loads when the CEDM is supported at the top, which are gradually decreased as the supports are lowered. The maximum loads of the supported CEDMs are 30~40% greater than those of the free standing CEDMs. As the support is lowered around 0.75 of H/L or less, the shear forces and the bending moments are decreased by as much as about 20% or less.

For bending moments, the decrease of the loads shows different profiles for each component at the different support elevation. The bending moments of the motor housing are greatly reduced by moving the support at 0.87 of H/L or lower height, but those of nozzles begin to decrease at 0.77 of H/L. Even though the seismic loads are greater than those of free standing CEDMs, it does not directly mean that the stresses exceed the allowable limits. That is, it only implies that the support is desirable to be located below 0.75 of H/L without increase of the loads. It seems that the changes of the seismic loads are closely related to the changes of the frequencies depending on the support height.

2.3 Acceptance of CEA Scram

As a major CEDM safety function, it is important to ensure the acceptability of CEA scram for the supported CEDM during earthquake excitation. The full drop of CEA in the fuel assembly should be achieved within the very short time. The criteria were established by the test in the past and given as a form of specific curve. The CEDM scram criteria provide the deformed limits satisfying the CEA drop time to insert and not to develop material failure of the pressure boundary components. Although the original criteria are given as a curve, they can be simply expressed with limited displacements at CEDM top and middle, and minimum radii of curvature. For the evaluation, ratio of displacement and bend radii of curvature from the analysis results are provided in Fig. 4.

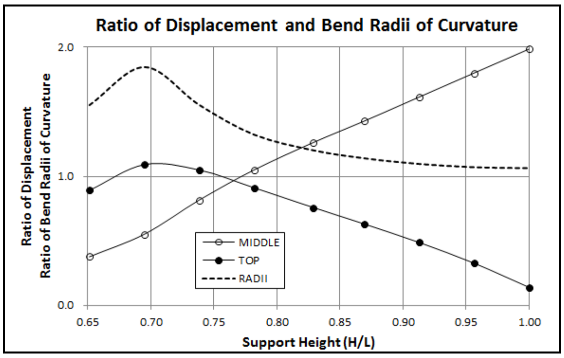

Fig. 4 Ratio of Displacement and Bend Radii of Curvature

The ratio in Fig. 4 means that displacements and bend radii of curvature from the analysis are divided by the specific criteria at the CEDM top and middle. In case that the displacement ratio exceeds 1.0, it implies that the displacements exceed the limits. However, the bend radii of curvature satisfy the scram criteria if the ratio exceeds 1.0. The displacement can be directly obtained from the post-processing of the analysis, but the radii of curvature are not readily presentable from the analysis so that they are developed from the relationship between bending moments and bend radii of curvature [3].

Based on the simple evaluation, displacements at the CEDM middle appear not to meet the criteria when the support is located at 0.78 of H/L or above. In addition, the displacements at CEDM top exceed the criteria when the support is located around 0.7 of H/L. The bend radii of curvature satisfy the requirement in all supporting cases. In a view of the displacement limits, the CEDM deformation could not meet the scram criteria except the support is located at 0.65 of H/L.

In order to proceed with further review, detailed scram criteria as a form of continuous deformation curve along the CEDM length are employed for evaluation. In the previous only two distinctive deformations at the CEDM top and middle were used for limited criteria, and it was failed to meet the criteria.

The continuous scram criteria curve is plotted in solid line as shown on Fig. 5.

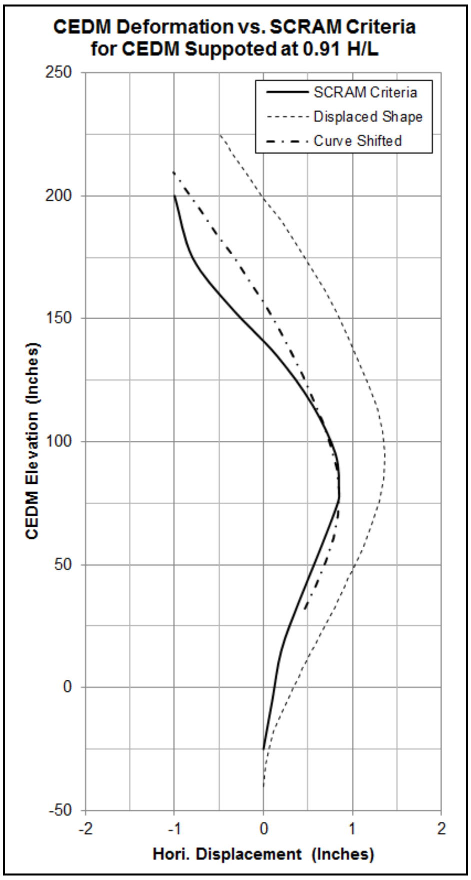

Fig. 5 Comparison of CEDM Deformation and Scram Criteria

The most extreme deformations are produced when the CEDM is supported at 0.91 of H/L. This result is chosen for comparison because the absolute sum of the displacements at CEDM top and middle is the greatest. Four guidelines for scram evaluation are established as follows;

A. The elevation at which the maximum displacement of the upper pressure housing or its minimum bend radius occurs should not be such that they occur close to the top of the motor housing. This point should be no lower than the corresponding minimum elevation used in CEDM scram criteria.

B. The minimum bend radius of curvature for the upper pressure housing, which should coincide with the maximum displacement, should not be smaller than minimum bend radii of curvature.

C. The arc length or the associated cord length over which curvature in the upper pressure housing occurs should not be smaller than corresponding lengths identified by the scram curve.

D. The lower tube end of the upper pressure housing should remain as straight as possible with respect to the motor housing to ensure proper entry of the ESA into the small diameter guide tube portion of the motor housing.

The displaced shape in Fig. 5 shows that the maximum displacement and minimum bend radius of the CEDM occurs at about 95 inches, which is almost same height with the criteria, and those occurs at the higher elevation than the top of the motor housing. The bend radii of curvature identified in Fig. 4 are greater than the minimum bend radii of curvature. The displaced shape is shifted to the criteria as close as possible in order to be compared with the arc length. The arc length of the shifted curve identified in dotted line is longer than that of CEA drop time curve. Therefore, it is verified that the lower tube end of the CEDM upper pressure housing remain straight. As a result, it is concluded that the supported CEDMs meet the guidelines of A through D.

Additionally it is desirable to locate the seismic supports where the displacements are relatively small at around 0.75 of H/L or lower height as shown in Fig. 4.

3. Conclusions

The seismic responses for the supported CEDMs have been analyzed with varying the support heights, and assessed by comparing with the loads of the free standing CEDM and scram criteria. The seismic support is capable of reducing the seismic loads only when the support is located at certain height. The guidelines are established to evaluate the deformation of the CEDM against the tested scram criteria. It is confirmed that the CEDM deformation in any supporting conditions satisfies the acceptance criteria. It is more desirable that the support is located around 0.75 of H/L or lower height with minimizing the displacements and loads, where is about 50 inches below the CEDM top.

The seismic response characteristics of the CEDM can be used to determine the proper location of the seismic support improving the seismic capability of the CEDM.

REFERENCES

[1] ANSYS, Inc., ANSYS Mechanical APDL Manual, Release 15.0, 2015.

[2] R. D. Blevins, Formulas for Natural Frequency and Mode Shape, Krieger, 1995.

[3] J. M. Gere and S. P. Timoshenko, Mechanics of Materials, 3rd Edition, Korean Edition, 1995.