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Assessment of High Frequent Vibrations

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1. Introduction

Structures and equipment systems have been subjected to high frequency motions from a variety of different sources like mining, quarry and construction blasting operations without damage. Where nuclear power plants have been subjected to local low magnitude earthquake ground motions, the resulting investigations have shown that plant structures and the associated equipment system are not affected by high frequency motion content [1].

As shown in Fig. 1, acceleration response spectra calculated out of fast impact induced vibrations (APC) show high exceedance of the design spectra (DBE) for nuclear buildings in the high frequency range above 20 Hz.

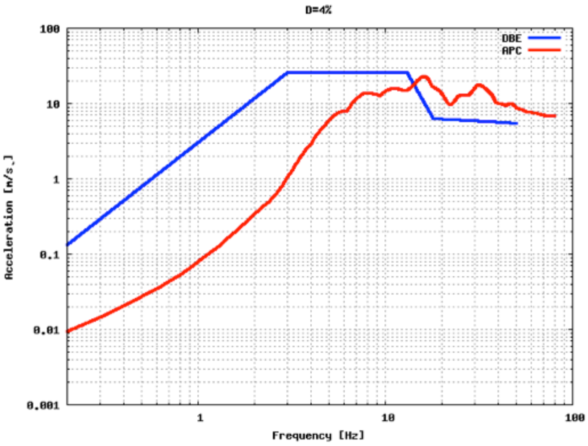

Fig. 1: Comparison of Design Spectra (DBE) and Fast Impact Spectra (APC)

Qualification testing of equipment systems has demonstrated that equipment can sustain unintentional high frequency motion associated with the operation of large shake tables [1]. Regulatory Guide 1.166 [2], developed in response to the issue of OBE exceedance at high frequencies, which concluded that frequencies over 10 Hz do not need to be considered in the determination of whether shutdown is warranted following a felt earthquake.

For this reason, a methodology for realistic calculation of fast impact induced vibrations has been developed and experimentally verified.

2. Filtering Methodology

The relation Sa=ω²Sd between the pseudo acceleration spectrum Sa and the displacement spectrum Sd leads to the conclusion that the high frequency accelerations are caused by extremely small displacements with a negligible participation in the total energy. Due to high frequency content in conjunction with low spectral displacements, a cut-off of the small displacements in the high frequency range is justifiable.

Out of these facts, a cut-off procedure [3], illustrated in Fig. 2 has been developed. A discrete fourier transformation is used to filter out the high frequency content of accelerations. The number of coefficients used to describe the functions is determined based on a defined spectral displacement e.g. 1mm or 0.1mm or a cumulative power value e.g. 90%.

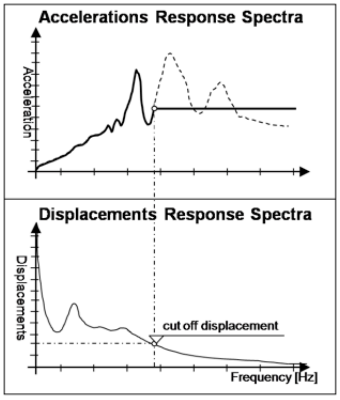

Fig. 2: Cut-off Methodology for Filtering Out of High Frequency Content of Accelerations

3. Experimental Verification

Experiments have been performed on a fully equiped switchgear, placed on a 2D shaking table. In total, 36 acceleration time histories have been applied in horizontal and vertical direction [3]. The dynamic responses of the tested device have been measured both in terms of accelerations and displacements.

Fig. 3: Tested Switchgear

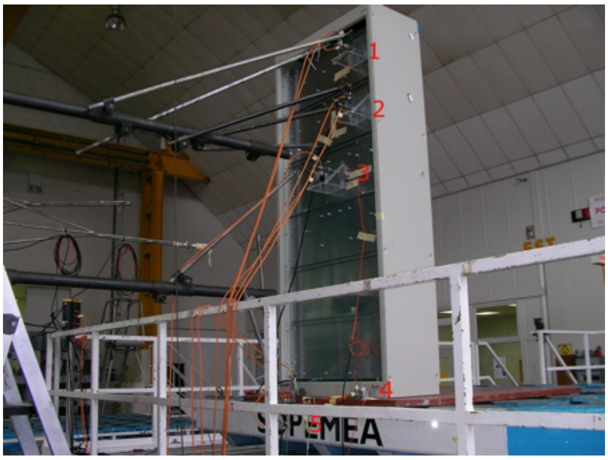

Fig. 4. Measuring Points, Equiped with Accelerometers and Displacement Transducers

3.1 Applied Excitation

Dynamic calculations have been performed for the load case fast impact on nuclear buildings and the dynamic responses in terms of acceleration time histories have been calculated at locations, where equipment is placed. These raw time histories have been filtered according to the methodology explained above. Both the raw and filtered acceleration time histories are applied as excitation to the shaking table.

The experiment will be illustrated on one pair of raw and filtered excitations.

The raw acceleration time history, shown in Fig. 5 in blue color, has been filtered and resulted in an acceleration time history, presented in red color.

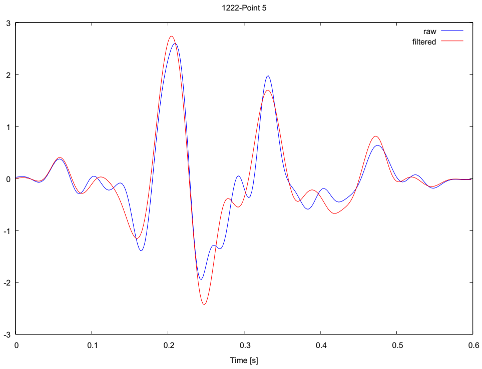

Fig. 5. Raw and Filtered Acceleration Time Histories

The process of filtering is shown in Fig. 6 through the fourier amplitudes of both time histories. The filtering process did cut-off the peak at approximately 30 Hz, while the rest of the frequency content is similar.

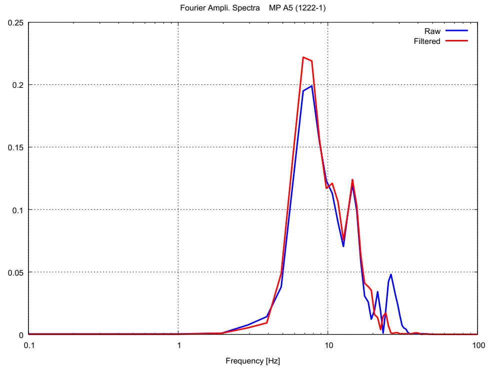

Fig. 6. Raw and Filtered Acceleration Fourier Amplitude Spectra

The acceleration response spectra (Fig. 7) of the raw and the filtered excitation are quite similar, except for frequencies around 30 Hz due to the filtering of the high frequency peak.

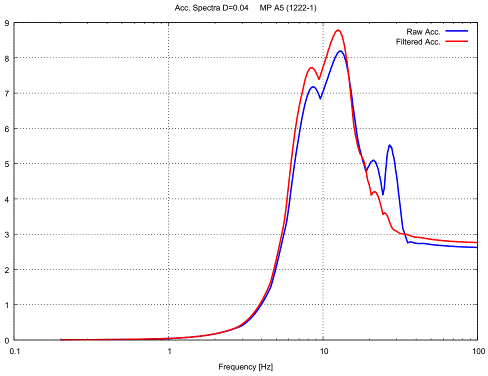

Fig. 7. Raw and Filtered Acceleration Response Spectra, D=4%

The similarity of the distribution of the energy, both of the raw and of the filtered acceleration time history, expressed through Arias intensity of the Husid plot, shown in Fig. 8, proves that a cut-off of small high frequent vibrations does not significantly change the properties of the time history.

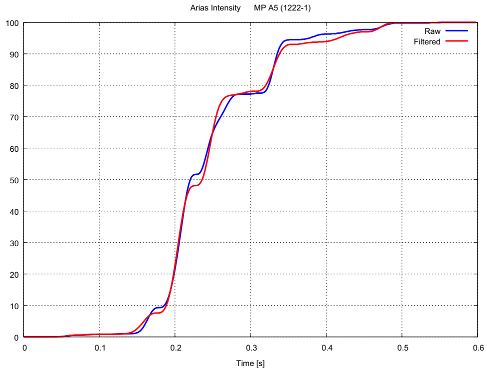

Fig. 8. Husid Plot of Raw and Filtered Acceleration Time Histories

The displacement time histories, corresponding to the acceleration time histories (Fig. 5) are presented in Fig. 9.

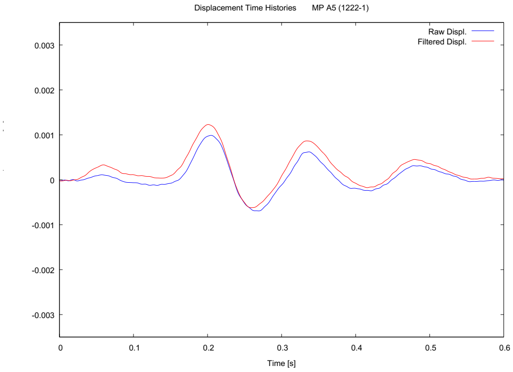

Fig. 9. Raw and Filtered Displacement Time Histories

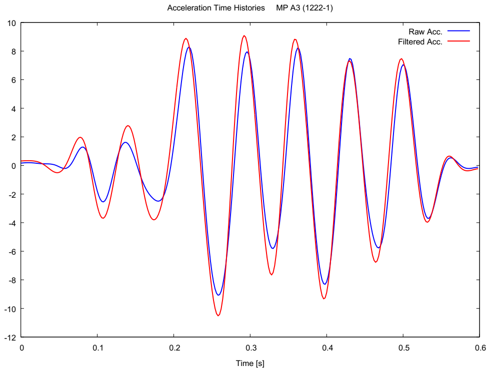

Fig. 10. Raw and Filtered Acceleration Time Histories

3.2 Measured Dynamic Response

During the experiment, the highest amplification of the acceleration time history, out of the 4 measuring points on the switchgear, has been measured in the middle of the switchgear.

In Fig. 10 to Fig. 14 the measured dynamic response at measuring point 3 are presented in the same order as for the excitation.

Out of these results, the following can be concluded:

- The response acceleration time histories both of the raw and of the filtered excitation are almost identic (Fig. 10)
- The peak of the raw acceleration time history at approximately 30 Hz almost dissapeared (Fig. 11)
- The response spectra of the raw and filtered time histories are almost identic (Fig. 12)
- The energy distribution of the raw and filtered time histories are almost identic (Fig. 13)
- The measured displacements of the raw and filtered time histories are almost identic (Fig. 14)

As there is almost no difference between the response of the switchgear to a raw and to a filtered excitation, it is evident that the switchgear absorbs the high frequencies of the excitation.

Following, the high frequencies do not affect the structural response. The high frequencies region can be neglected for the evaluation of forces and stresses.

The methodology of filtering the high frequency content of fast impact induced vibrations is appropriate and corresponds to the real processes, which take place in a switchgear, subjected to high frequent excitation.

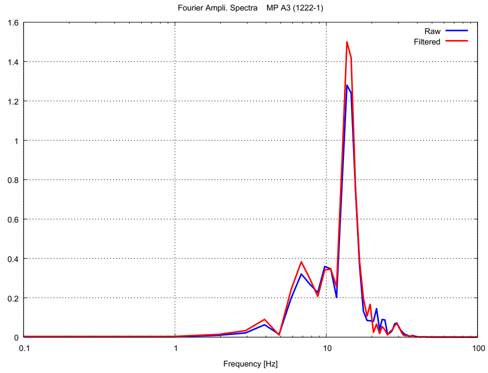

Fig. 11. Raw and Filtered Acceleration Fourier Amplitude Spectra

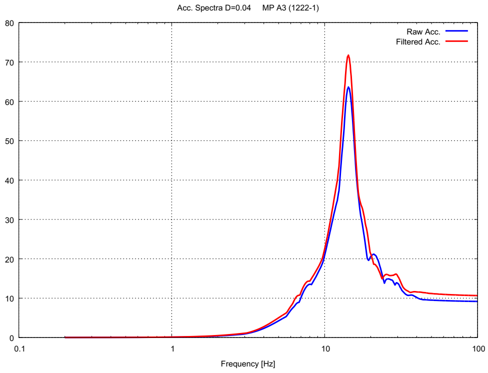

Fig. 12. Raw and Filtered Acceleration Response Spectra, D=4%

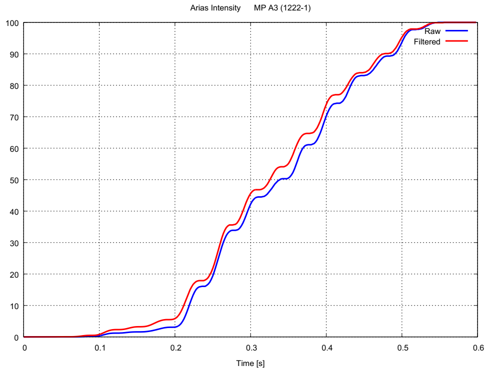

Fig. 13. Husid Plot of Raw and Filtered Acceleration Time Histories

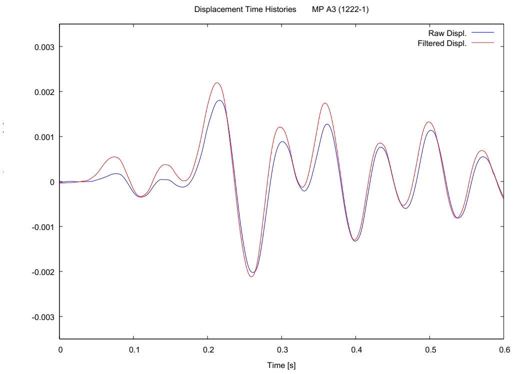

Fig. 14. Raw and Filtered Displacement Time Histories

3. Conclusions

There is both analytical and empirical evidence [1] that short duration, high frequency excitations are not damaging power plant equipment. The empirical evidence, presented by EPRI [1] is extensive and broad in its origins:

- Mining, quarry and construction blasting data support the lack of high frequency effects
- Earthquake experience data at NPPs support the lack of high frequency effects
- Northeast Ohio earthquake of 1986 (Perry Plant)
- South Carolina Monticello Reservoir events of 1978/1979 (Summer Plant)
- 1989 Slovenia Earthquake (Krško Plant)
- Shake table equipment qualification data support the lack of high frequency effects
- Operational vibration test data support the lack of high frequency effects

A methodology for realistic calculation of fast impact induced vibrations, which are short and high frequent excitations, has been introduced.

REFERENCES

[1] Electric Power Research Institute, “Program on Technology Innovation: The Effects of High Frequency Ground Motion on Structures, Components, and Equipment in Nuclear Power Plants”, Report 1015108, June, 2007

[2] US Nuclear Regulatory Commission, “Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Postearthquake Actions”, Regulatory Guide 1.166, USNRC, March, 1999

[3] Reduction of External Hazard (Fast Impact) Induced Vibrations, V. Vlaski, A. Fila, O. Schneider and D. Papandreou, TINCE, Paris, 2013