Coupling the Modeled Structural Transmissibility of a Used Nuclear Fuel Conveyance to Over the Road Data – 16215

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ABSTRACT

The U.S. Department of Energy Office of Nuclear Energy (DOE-NE), Office of Fuel Cycle Technology, has established the Used Fuel Disposition Campaign (UFDC) to conduct research and development activities related to storage, transportation, and disposal of used nuclear fuel (UNF) and high-level radioactive waste (HLW). The mission of the UFDC is to identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of used nuclear fuel and HLW generated by existing and future nuclear fuel cycles. The Storage and Transportation staff within the UFDC is responsible for addressing issues regarding the long-term or extended storage (ES) of UNF and its subsequent transportation.

Current information is insufficient to determine the ability of UNF, including high-burnup fuel, to withstand shock and vibration loads that could occur when UNF is shipped by rail from nuclear power plant sites to a storage or disposal facility after extended storage. In order to make this determination, the magnitude of the transportation loads transmitted to the UNF must be quantified. Previous preliminary modeling work has shown how the structural transmissibility of the transport system can affect the magnitude of these loads and the importance of modeling all aspects of the transport system (i.e. rail car, transport cradle, cask, canister, and fuel). The work presented herein proposes a methodology for determining the structural transmissibility of a hypothetical transport system, and conditions existing over the road test (OTR) data to predict the performance of the hypothetical system. This method utilizes the modeled frequency response of the hypothetical system to scale the existing OTR acceleration data. This work will be relevant in creating models of a UNF conveyance during transport. As such, preliminary work in coupling the rail vehicle dynamics code NUCARS©, a general purpose multi-body rail vehicle dynamics simulation package developed by Transportation Technology Center Inc. (TTCI), to existing models of UNF during transport are also discussed herein.

INTRODUCTION

The mission of the Used Fuel Disposition Campaign (UFDC) is in part to develop the technical bases needed to support extended storage of used nuclear fuel and associated transportation. The objectives of the transportation activities are to address identified high-priority technical issues as well as to support the Nuclear Fuels Storage and Transportation Planning Project efforts to prepare for the large-scale transportation of UNF with an initial focus on removing UNF from the shutdown reactor sites. This includes developing the technical basis for the transport of high-burnup used nuclear fuel (HBU UNF) and the transport of all used nuclear fuel after extended storage. This work will focus on planned field-testing to assess realistic loading on the fuel rods and assemblies during Normal Conditions of Transport (NCT) and modeling to which supports this testing effort, in order to obtain data needed to evaluate the integrity of the UNF.

As discussed in a report by Adkins et al. [1] on used nuclear fuel performance characterization under U.S. Nuclear Regulatory Commission (NRC) regulations, it is not sufficient for UNF to simply maintain its integrity during the storage period. It must maintain its integrity in such a way that it can withstand the physical forces of handling and transportation associated with restaging the fuel and moving it to a different location (such as an interim storage site). Hence, understanding mechanical performance under cumulative loading stemming from storage, transfer from storage container to transport container, and normal conditions of transport is necessary. This establishes part of the safety basis by maintaining the fuel confining boundary (geometry) and criticality safety. Because of this, an understanding of the mechanical loads on used nuclear fuel, cladding, and key structural components of the fuel assembly during normal conditions of transport, and the mechanical response of the UNF and assembly components to these loads is essential.

As discussed, the conveyance design may greatly affect the loads transmitted to the fuel [2]. To better understand this staffs at Pacific Northwest National Lab (PNNL) have begun examining how existing OTR data, which contains information about the magnitude of the input loads, can be scaled with the modeled structural transmissibility of an untested conveyance design. This will provide information concerning how the modeled system would perform when subject to the same input loads as the tested conveyance.

In addition, the input loads that the conveyance experiences will affect the loads transmitted to the fuel. These input loads are generated at the rail wheel interface during transport, and may differ greatly depending on the speed of the train and the condition of the rail. To better understand this, PNNL is in the process of developing a modeling methodology which will allow the user to couple the rail vehicle dynamics code NUCARS© with existing models of UNF during transport. This methodology will allow the user to subject a UNF conveyance to various track conditions and train speeds and predict the response in the fuel.

BACKGROUND

In 2014, Sandia National Laboratories (SNL) provided valuable information regarding the loads transmitted through the conveyance system to the fuel assembly [3]. For practical reasons, the testing could not be performed on an actual used nuclear fuel conveyance system, so a surrogate test conveyance system was configured using a flatbed trailer and large blocks of concrete to achieve a realistic mass representation. The system was intended to mimic the total mass of an existing used fuel highway conveyance.

Analysis of the 2014 OTR data showed that there may be an attenuation or amplification of the input loads, due to the structural transmissibility of the system. The results from this testing, showing the effects of structural transmissibility are shown in Figure 1.

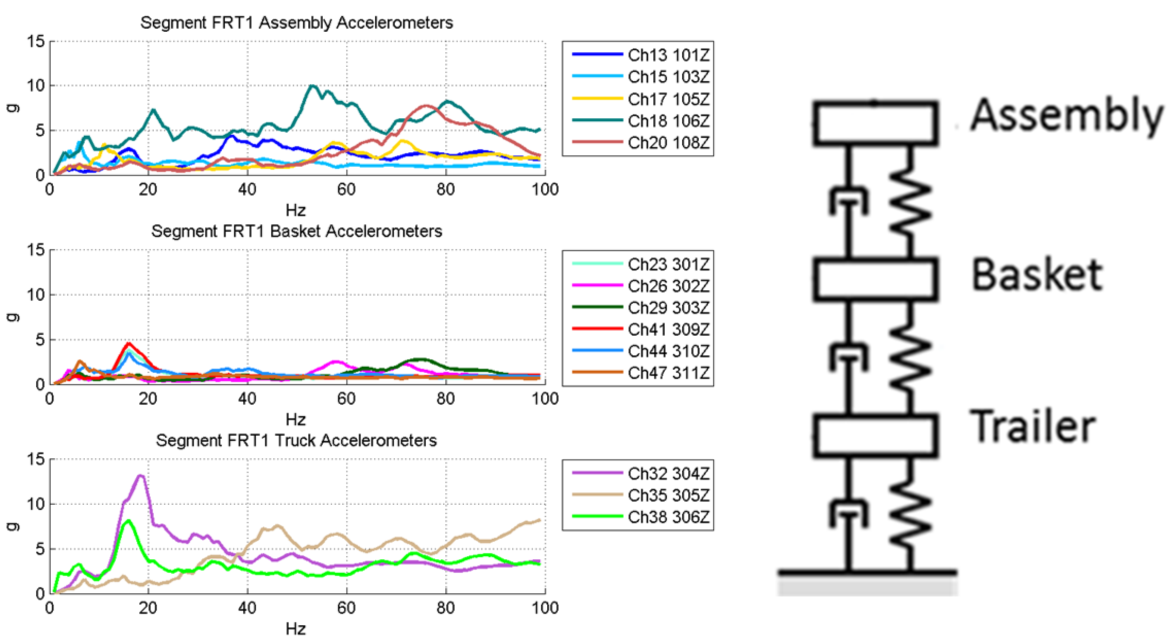

Figure 1: Conveyance Accelerometer Responses

The results from this work and subsequent modeling of the system indicated that the structural design of the conveyance may greatly effect the magnitude of the loads transmisted to the fuel [4]. Thus it is necesarry to develop techniques, for determining how a different design may behave under the similar loading conditions. Specifically, a method for scaling the OTR data above with the modeled frequency response of a hypothetical system is described herein.

HIGHWAY CONVEYANCE COMPARATIVE TRANSMISSIBILITY

Previous work has shown that the dynamic characteristics of a UNF conveyance may affect the magnitude of the loads transmitted through the conveyance to the). The phenomenon, which is responsible for the amplification or attenuation of base input loads which travel through a structure, is known as the structural transmissibility [5].

In order to better understand how structural transmissibility affects a UNF conveyance, two models have been developed. The first model represents a system which was used for preliminary over the road (OTR) testing by SNL [3, 6]. A simplified model of this system is shown in Figure 2. It consists of two concrete blocks, a simulated basket, and a blended mass surrogate representing the fuel assembly.

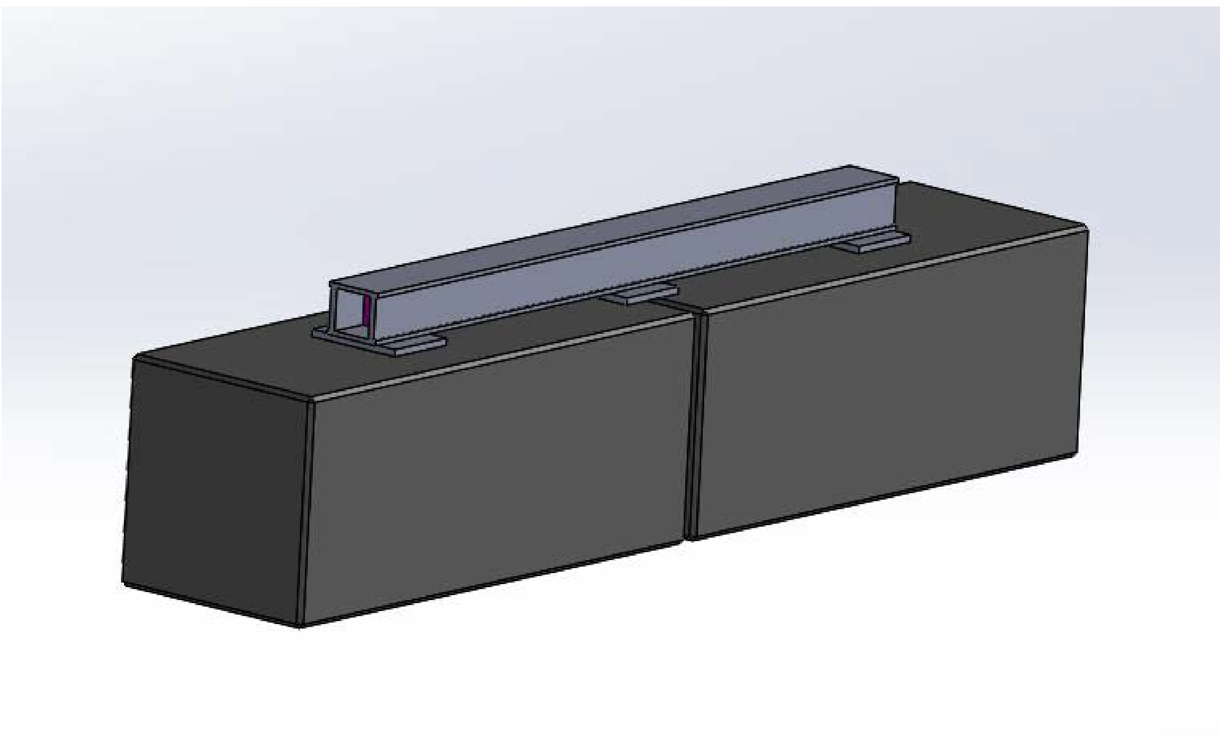

Figure 2: Sandia Test Conveyance

The SNL conveyance was compared to a currently used UNF conveyance; this conveyance represents a realistic transport system [6]. It consists of a transport cradle, cask, basket, and blended mass surrogate representing the fuel. A simplified model of the realistic conveyance is shown in Figure 3.

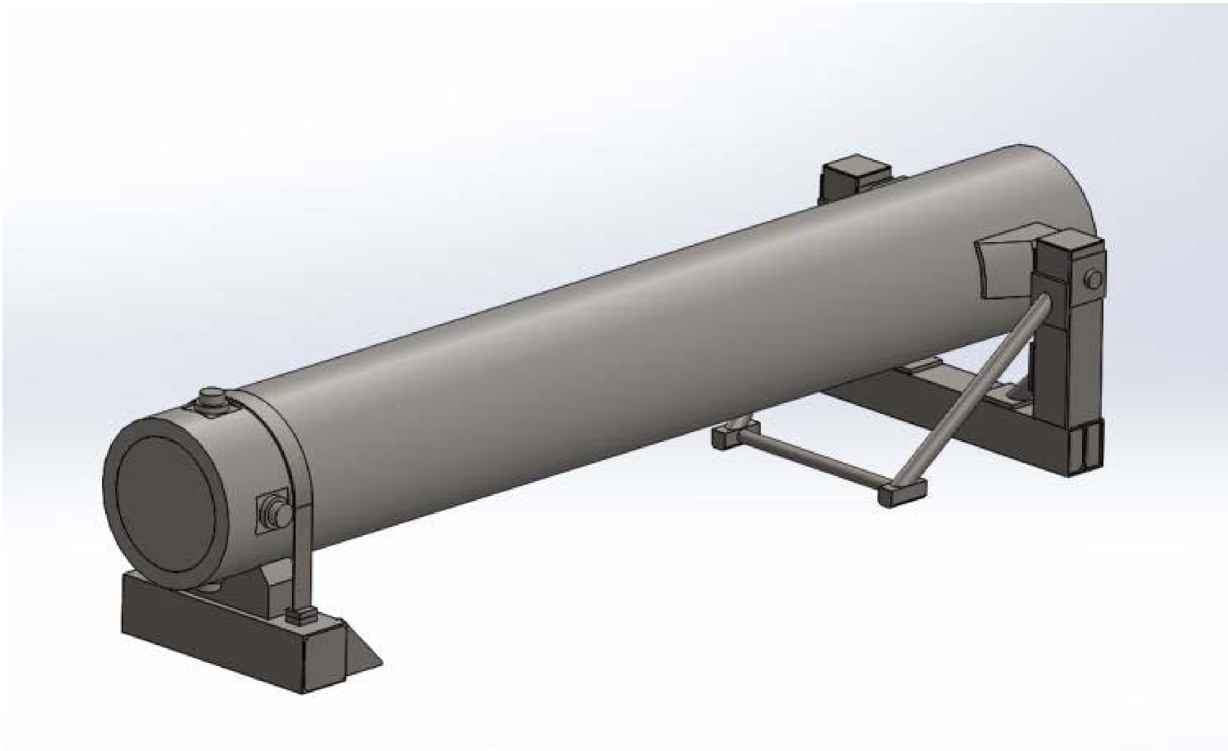

Figure 3: Realistic Conveyance

For comparison, each model had nearly equivalent total masses. The SNL conveyance had a total mass of approximately 48,000 lbs, and the realistic conveyance had a total mass of approximately 52,000 lbs.

In each case, the models were subjected to a modal analysis and random vibration analysis in ANSYS Workbench 15. The first 15 modes in the vertical direction are shown in Table 1. The modal results show that no significant modes exist for the SNL conveyance below 231 Hz and that the largest mode occurs at 369.9 Hz. Contrasting this, the realistic conveyance has a large mode at 36.6 Hz with a second important mode at 27.5 Hz.

Table 1: Modal Results

SNL Conveyance			Realistic Conveyance		
Mode	Frequency	Ratio	Mode	Frequency	Ratio
1	231.136	0.00104	1	8.85205	0.000146
2	250.533	0.000344	2	9.31654	0.000148
3	297.093	0.199762	3	21.205	0.000359
4	334.351	0.003201	4	27.5459	0.530824
5	344.778	0.000637	5	36.6499	1
6	351.037	0.001242	6	38.6679	0.091569
7	369.91	1	7	66.6809	0.096019
8	410.528	0.003257	8	70.2788	0.002166
9	464.107	0.000027	9	78.253	0.00132
10	466.077	0.00962	10	88.2684	0.001229
11	494.523	0.001507	11	92.3141	0.001181
12	549.533	0.016946	12	92.4925	0.002578
13	554.744	0.386349	13	111.577	0.005473
14	557.091	0.007955	14	112.302	0.006233
15	617.809	0.00115	15	114.949	0.003379

The random vibration analysis allows the user to compare the response Power Spectral Density (PSD) at any location in the structure for a given base input PSD. The base input PSD is shown in Figure 4 and was used in previous shaker table work performed by SNL [7]. The base input PSD was applied in the vertical direction

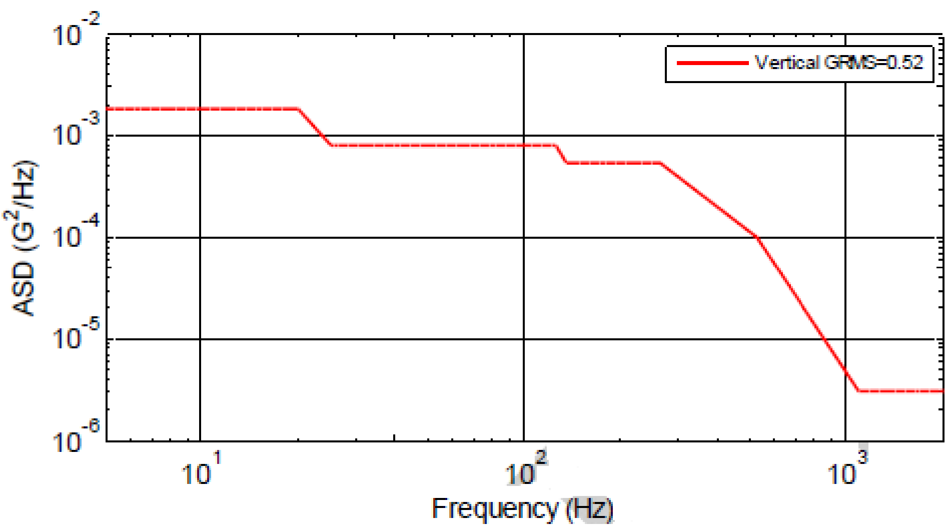

Figure 4: Input PSD

For the SNL conveyance and realistic conveyance, the response PSD was measured at the center of the basket at the interface between the blended mass fuel surrogate and the bottom surface of the basket. The measured response PSDs and input PSD are shown in Figure 5. This analysis shows that the realistic conveyance shows an amplification of input loads from 5-68 Hz, and a large attenuation above 68 Hz. The SNL conveyance tracks the input PSD from 5-100 Hz, amplifies the input from 100-350 HZ, and attenuates the input loads above 350 Hz.

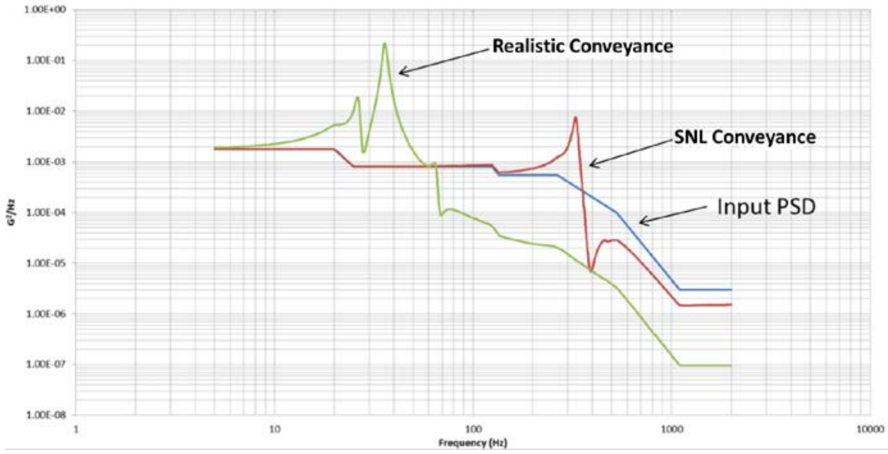

Figure 5: Response PSDs

The results from the modal analysis and random vibration analysis demonstrate that the realistic conveyance behaves in a distinctly different manner from the SNL conveyance. This indicates that the structural characteristics of the conveyance may play an important role and affect the magnitude of the loads transmitted to the fuel.

HIGHWAY CONVEYANCE COMPARISON

The previous section has demonstrated that the dynamic characteristics of the conveyance structure can affect the magnitude of loads experienced by UNF during transport and that each conveyance is likely to have different transmissibility characteristics. OTR testing can be used to determine the loads transmitted to the UNF under various transport circumstances. However, it would be impractical to perform OTR testing for every conveyance design, under all known road or rail transport condition. To address this issue, PNNL staff have developed a methodology for scaling existing OTR data with the modeled dynamic characteristics of a hypothetical conveyance. To demonstrate this methodology, the scaling of OTR test data for the SNL test conveyance with the modeled dynamic characteristics of the realistic conveyance is presented in this section.

Figure 6 shows a portion of the measured acceleration time history from OTR testing that was performed in FY14 [3, 4], which will be scaled by the modeled structural transmissibility of the untested realistic conveyance.

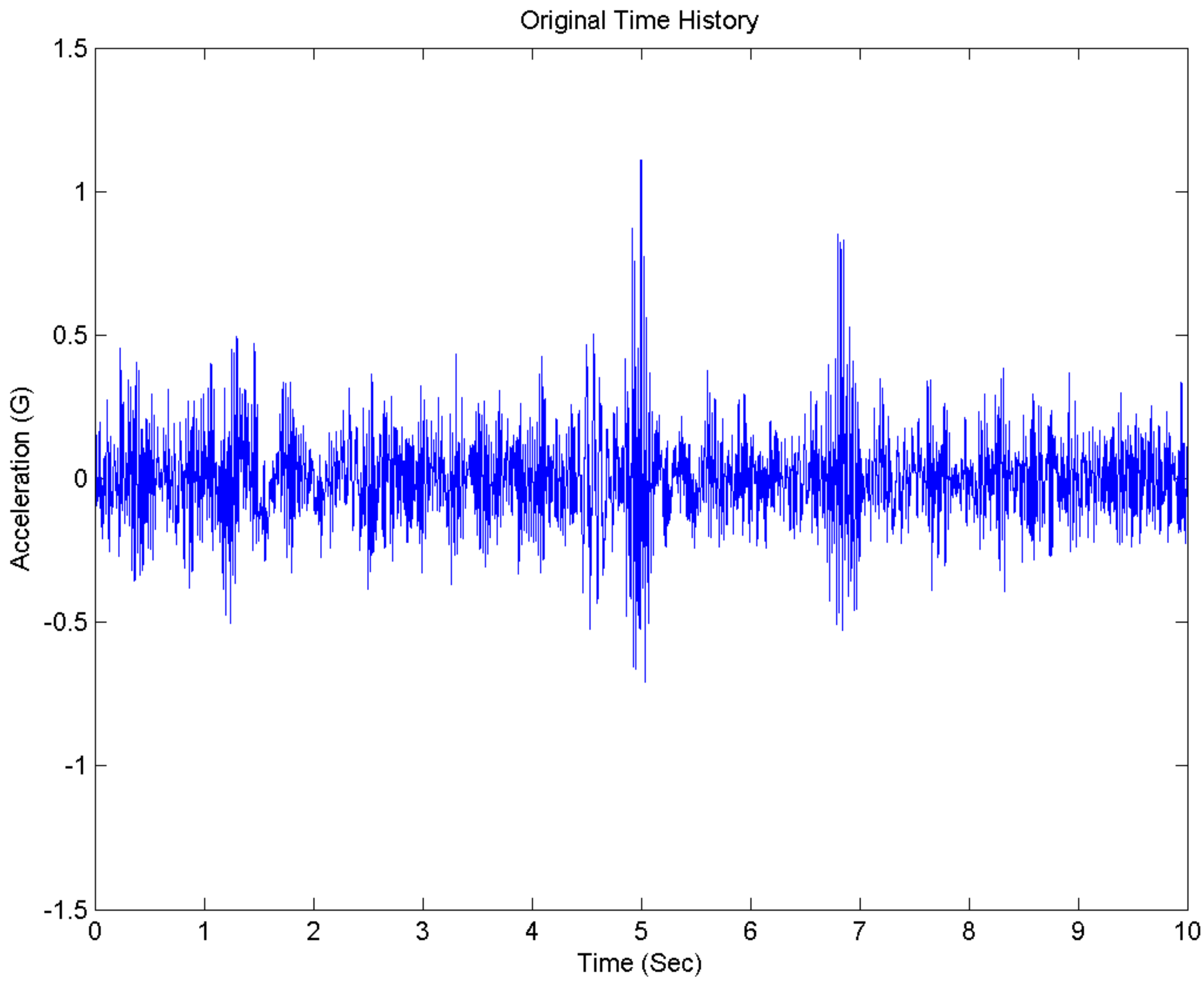

Figure 6: OTR Acceleration Data

For both the SNL conveyance and realistic conveyance, a harmonic analysis was performed in ANSYS Workbench 15. In each case, a 9.806 m/s^2 base excitation was applied from 0-500 Hz, and the system damping was set to 0.03. This frequency range was chosen because the OTR data shown in Figure 6 was filtered with a low pass filter with a 500 Hz cutoff frequency. The harmonic analysis was used to generate the amplification ratio of the realistic conveyance to the SNL conveyance. The results from the harmonic analysis are shown in Figure 7, and the amplification ratio is shown in Figure 8.

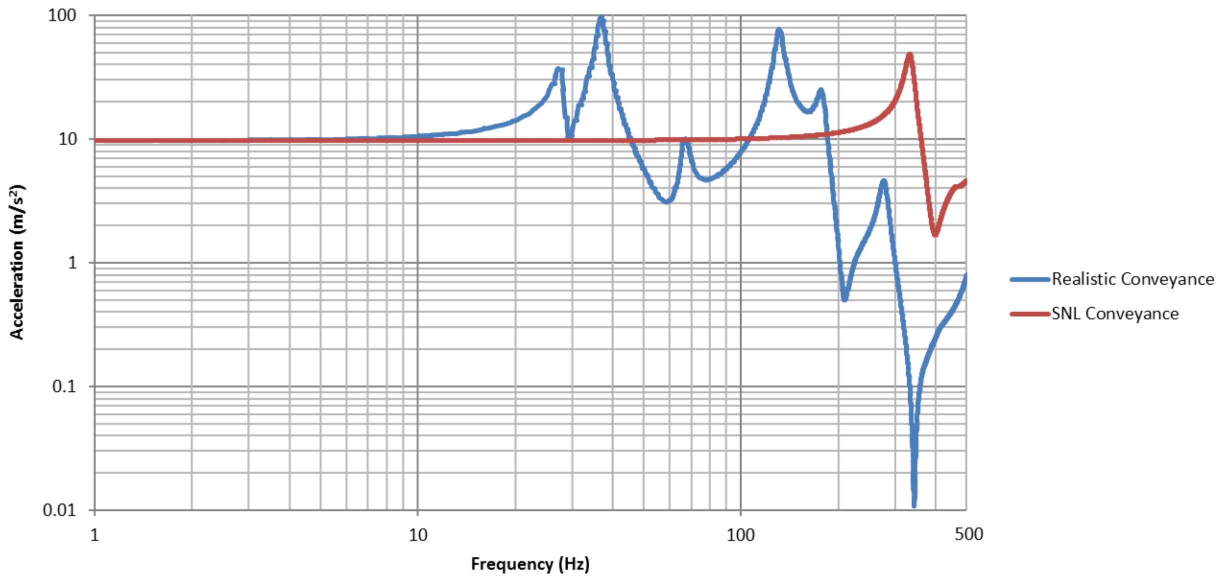

Figure 7: Harmonic Analysis of the SNL & Realistic Conveyance

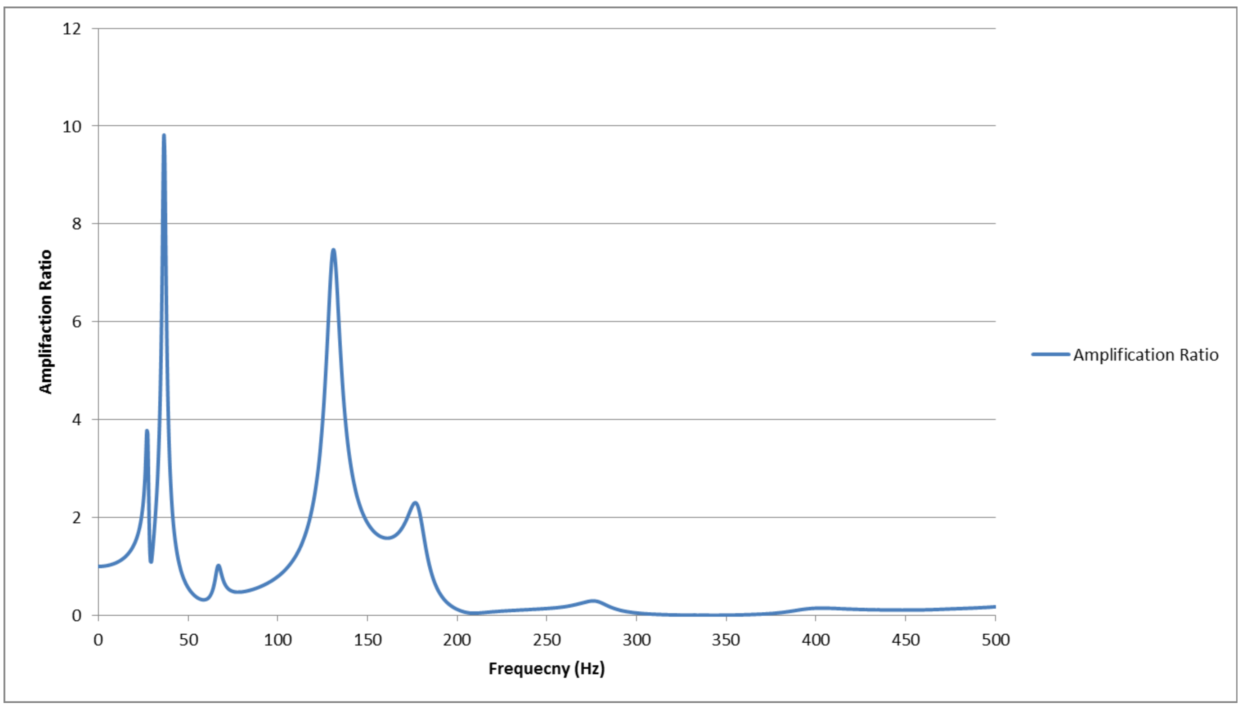

Figure 8: Amplification Ratio

A Fast Fourier Transform (FFT) was then performed on the original time history shown in Figure 6. In the frequency domain, between the 0 and 500 Hz the OTR test data was scaled with the amplification ratio. An overlay, in the frequency domain, of the original OTR data and the scaled OTR data is shown in Figure 9.

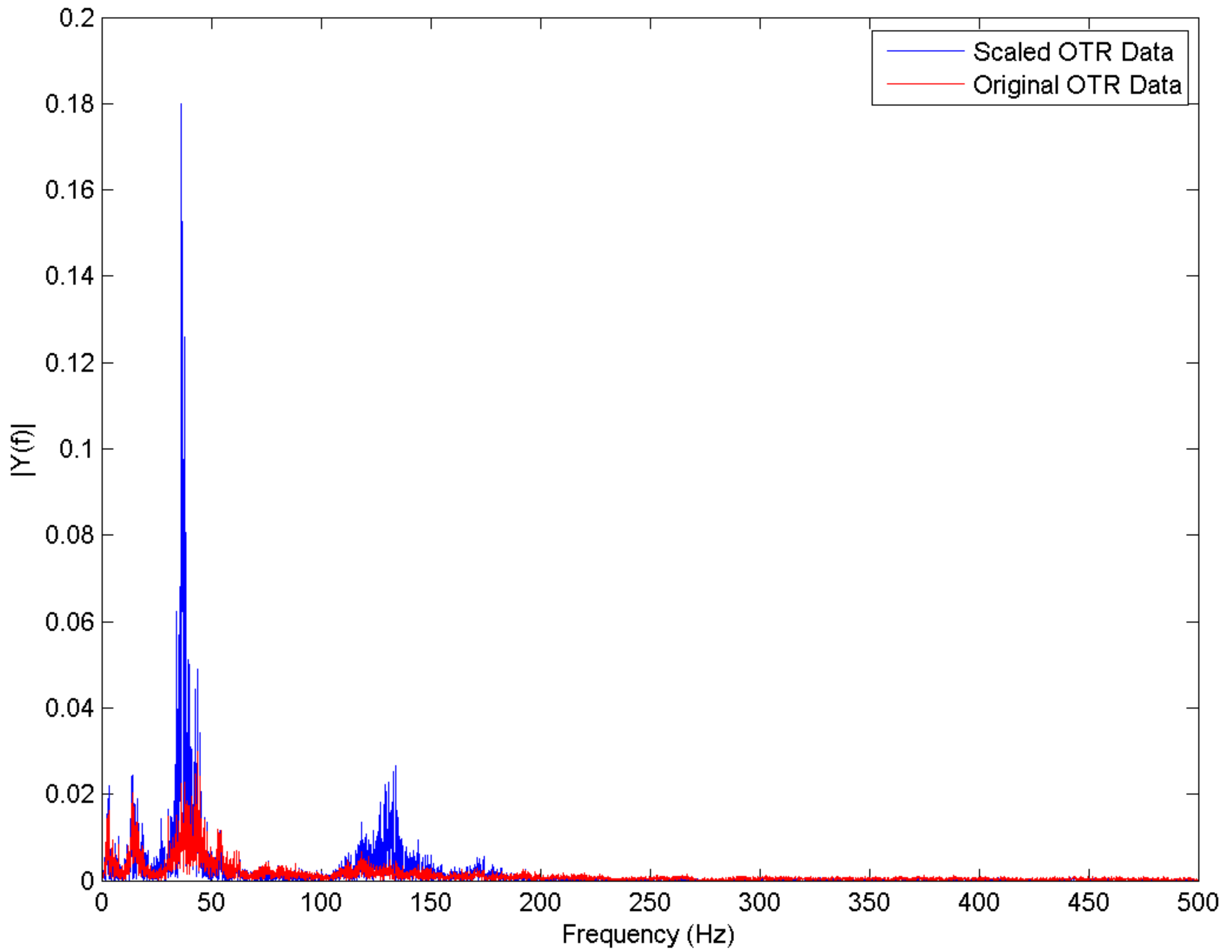

Figure 9: Original and Scaled OTR Data

The inverse transform was then performed on the scaled OTR data, yielding a new time history that incorporates the dynamic characteristics of the realistic conveyance. An overlay of the new scaled acceleration time history and the original acceleration time history is shown in Figure 10. Figure 10 clearly shows that the magnitude of the loads in the acceleration time history has been amplified by the modeled structural transmissibility of the realistic conveyance.

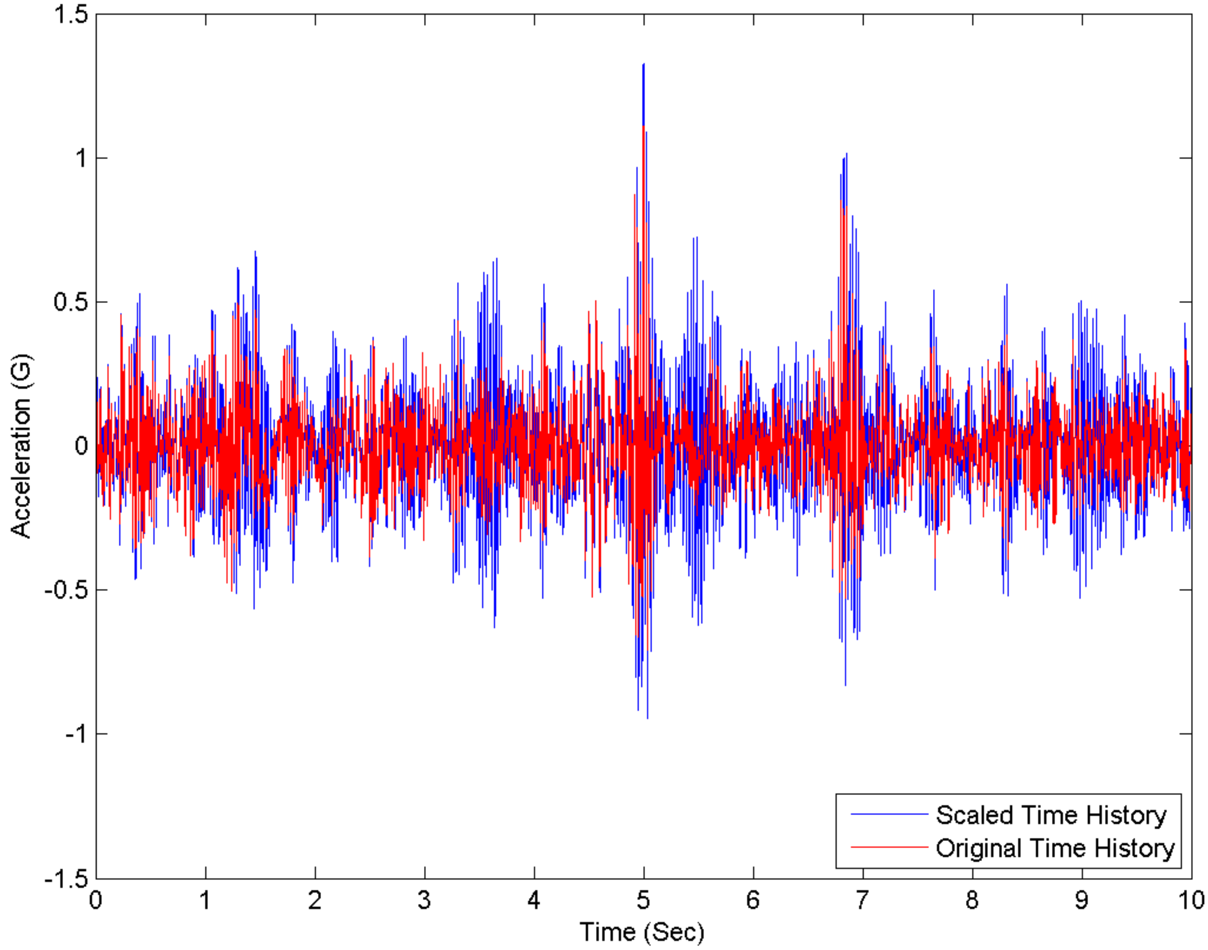

Figure 10: Scaled and Original Acceleration Time History

The scaled acceleration and original acceleration time history from Figure 10 was used as base excitation in a finite element model of the basket and fuel assembly that was developed in 2013-2014 [6].

FUTURE WORK

In FY 16, PNNL will begin using some of the methods described herein to couple existing models of UNF during transport to specific rail car models in the NUCARS© modeling suite [8]. NUCARS© is a general multi-body rail vehicle dynamics simulation package which allows the user to model different rail car configurations, track geometries, conveyance transportation speeds, and other factors that would affect the ride quality of a UNF conveyance [9]. This coupled modeling methodology will allow the user to test a hypothetical UNF conveyance under various rail conditions.

Currently this work is progressing by examining four separate but similar modeling methodologies. The first involves preforming a modal analysis in ANSYS of the rail car, cradle, and cask and then inputting this as one lumped flexible mass into NUCARS©

with the natural frequencies identified by the ANSYS modal analysis. The second would require performing a modal analysis in ANSYS of each components of the conveyance and inputting these discreetly into NUCARS© with the natural frequencies identified by the ANSYS modal analysis. The third would be similar to the 1st and 2nd option, but would require loading each component into the NUCARS© with the nodal FEM information obtained from ANSYS. The fourth option would involve measuring the acceleration time histories predicted by NUCARS© at the rail car center bowls, and inputting these into a transient structural model of the rail car, cradle, and cask in ANSYS. These methodologies will be compared in a coming study.

CONCLUSIONS

Described herein are methods for modeling how UNF preforms during transportation. A frequency scaling methodology was presented to better understand how the structural transmissibility of the conveyance components affects the loads. This method allows the user to better understand the accelerations seen by the conveyance due to changes in transmissibility predicted by modeling. In addition, plans for developing a coupled model of a UNF rail conveyance were presented.

These models and future OTR testing of a rail conveyance [8, 10] are being pursued by the UFDC program, and will aid in developing a strong technical basis for the safe transportation of UNF.

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