Machine Learning Based Surrogate Modeling of Human Vehicular Vibration

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- Finite Element Simulations
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Introduction

- Vibration exposure is a known cause of several human medical issues, such as short-term and long-term pain and injury in the back and spine [1].
- This exposure can be found in several fields of work, including agriculture, transportation, forestry, and construction [2]. The military also has this issue, as military vehicles are often driven in terrains that expose the drivers to **whole-body vibration** (WBV) that affect the driver's comfort and health [3].
- It has been found that the resonance frequency of the human spine occurs at around 4.5-5 Hz [4], and many vehicles vibrate at a frequency close to the natural frequency of the human body [5].

Military Humvee

From https://en.wikipedia.org/wiki/Humvee, 9/30/22

[1] N. Arora, et al, *J. Electromyogr. Kinesiol*, 2013.
[2] M. Yung, et al, *PLoS ONE*, 2017.
[3] D. J. Park, et al, Int. *J. Ind. Ergon.*, 2019.
[4] T. Hansson, et al, *Clin. Biomech*, 1991.
[5] M. H. Pope, et al, *J. Biomech*, 1987.

Study Objectives

- Investigate the effects of whole-body vibration (WBV) on injury to the spine
- **Establish a method to assess injury risk due to WBV.**

Approach

- Finite element (FE) method used for simulations
  - Human body models settled onto a care seat model
  - WBV vibration inputs will be used to obtain spine stresses and strains
  - Injury risk criteria calculated to determine injury risk level
- Machine learning-based surrogate models
  - Frequency and amplitude combinations used as WBV inputs
  - FE simulation and injury risk results used as to build model

FE Simulation Models

- LS-Dyna Finite Element Simulation software package
  - Human models placed into seat model using seat deformer tool within LS-PrePost
- Human Models (Elemance)
  - 50^{th} percentile male human models
  - Simplified version (840,000 elements)
  - Detailed version (2,300,000 elements)
- Seat from 2021 Nissan Rogue

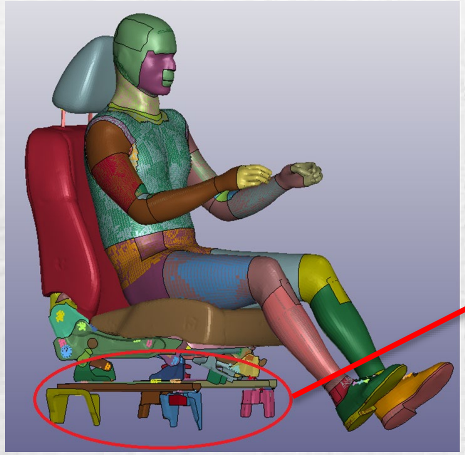
Nissan Rogue Seat Model

Human Detailed Model

From Elemance: "Virtual Human Models", https://www.elemance.com/models/

FE Simulations

- A settling period in the simulation is used to allow the human model to relax into the seat.
- Following this settling period, a **vibrational input is applied to the bottom components of the seat** to allow a realistic portrayal of the vibrations propagating through the seat.
- A seatbelt will be added onto upcoming simulations within this project to have a more accurate portrayal of the real-world case.

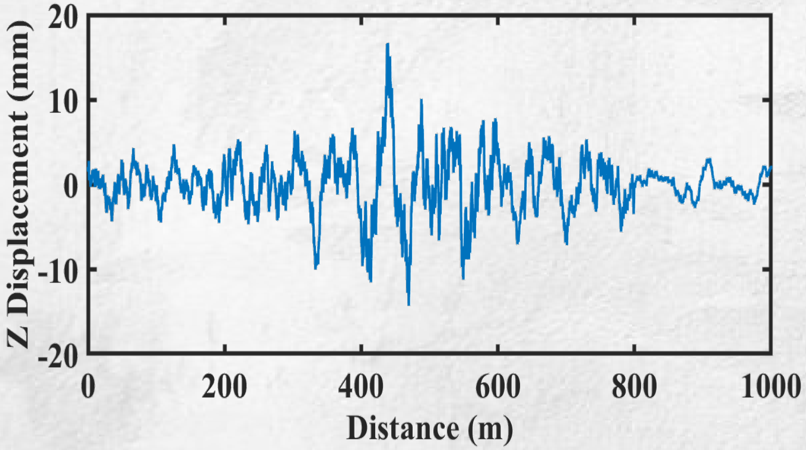


Seated Human Model (Detailed)

Parts with vibration input

Vibration Inputs

- The vibration inputs will be **time (ms) vs displacement (mm)** data generated using
  - CREATE-GV (military vehicles)
  - Non-stationary Laplace road terrain generator [1] paired with an 8 DOF car model [2] to create vibration profiles



Generated Road Profile

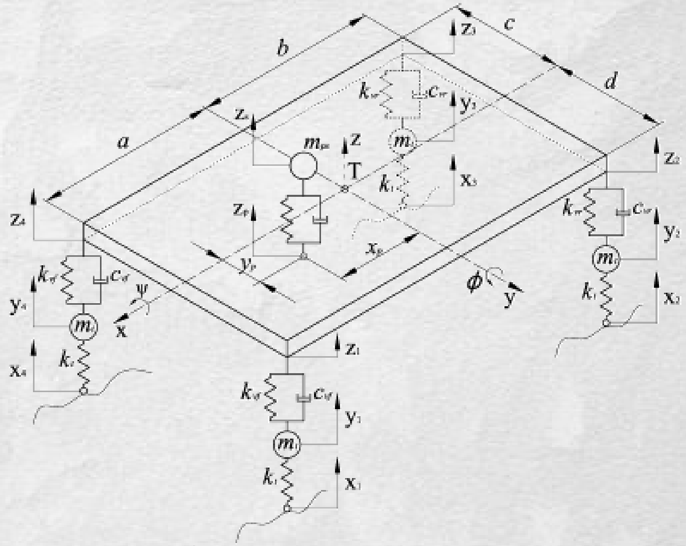


Diagram of 8 DOF Car Model [2]

[1] P. Johannesson and I. Rychlik, *Int. J. Veh. Des.*, 2014
[2] R. Žigulić et al, *Trans. FAMENA*, 2009.

Approved for Public Release

Injury Criteria

- For the injury risk factor (IRF), three specific stresses on the lumbar spine will be needed
  - σ_{static} (compressive stress)
  - $\sigma_{dynamic}$ (dynamic stress)
  - $\sigma_{ultimate}$ (ultimate stress - 41.668 $\rho^{1.9}$ [2])

- The IRF has three tiers of injury risk
  - IRF < 30% is a low risk of injury
  - 30% < IRF < 50% is a moderate risk of injury
  - IRF > 50% is a high risk of injury

$$\sigma_{dynamic} = B\frac{\sqrt{1+(2*\xi)^2}}{2*\xi}\frac{A(f)*M}{s}*cos(\theta)$$

- The variables for the dynamic stress [1]
  - M = equivalent mass
  - A(f) = applied acceleration amplitude to the seat at the natural frequency (f)
  - S = cross-sectional area at the intervertebral disc
  - θ = posture angle
  - ξ = damping rate
  - B = statistical constant

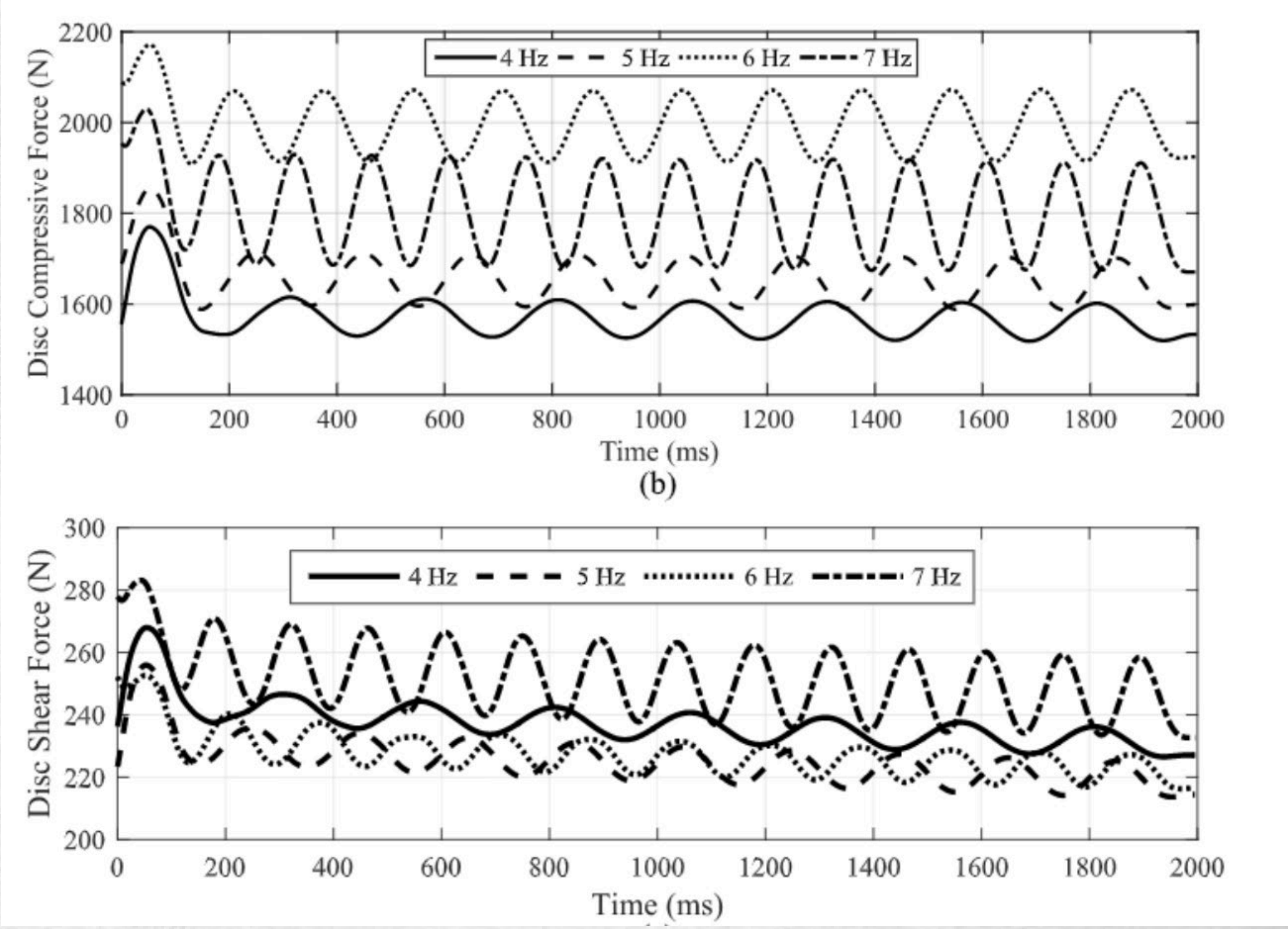
$$\text{IRF} = 100 * \frac{\sigma_{static} + \sigma_{dynamic}}{\sigma_{ultimate}}$$

[1] Ayari et. al, *Revue Internationale sur l'Ingénierie des Risques Industriel,* 2008.
[2] Ayari et al, *Journal of Sound and Vibration*, 2009.

Injury Criteria

- Further work will be done with the FE models to **identify the natural frequencies of the spine model**.

- These natural frequencies can be used to **avoid resonance** and see how resonance impacts the injury risk of the spine.

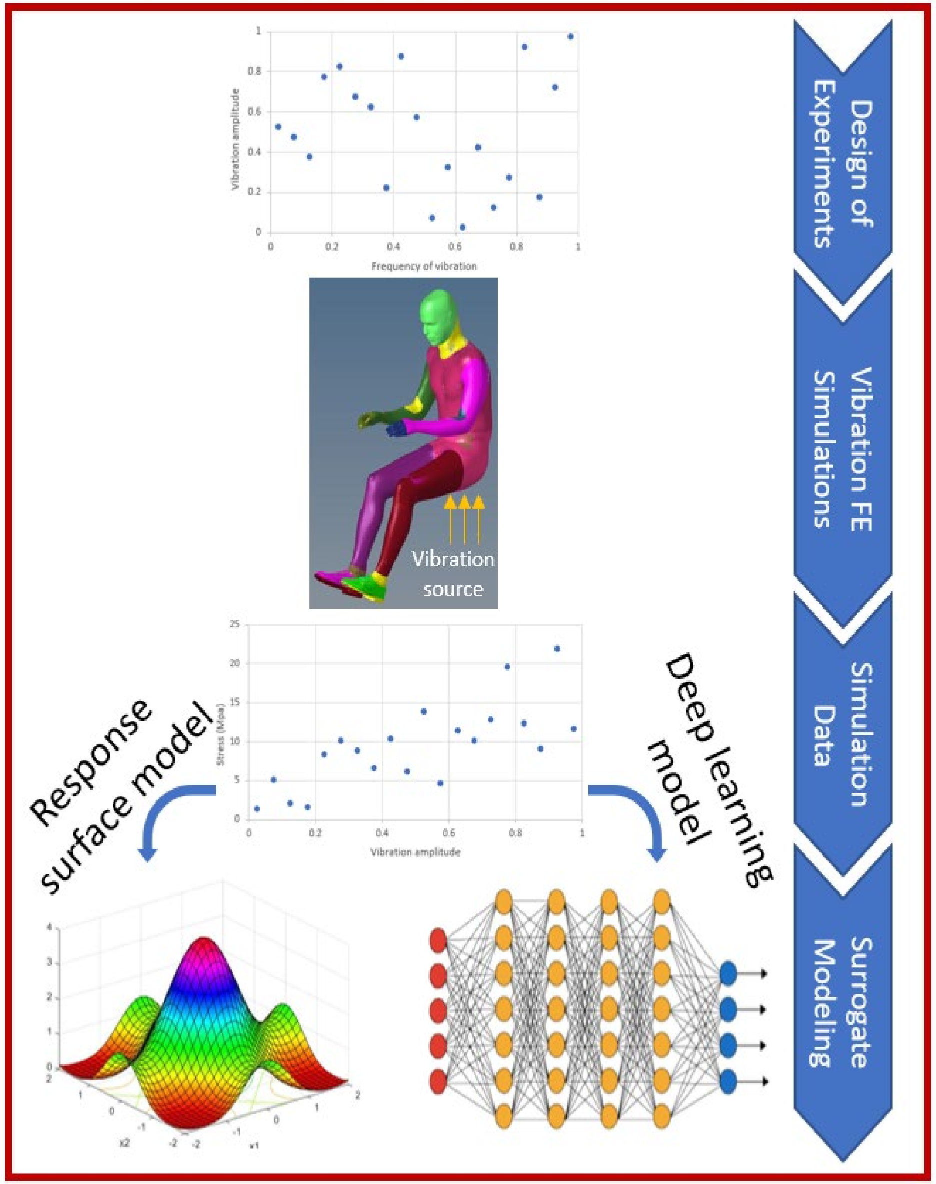


Compressive and Shear Forces in the Spine at Different Vibration Frequencies [1]

[1] S. Amiri, et al, *Comput. Biol. Med.*, 2019

Surrogate Modelling

- Finite element simulations coupled with surrogate modeling techniques
- Latin hypercube sampling used to design experiments for conducting the FE simulations
- Surrogate modeling employed to **establish a relationship between the finite element inputs (vibration variables) and outputs (injury risk metrics)**
- Outcome is an assessment method to predict risk of injury associated with vehicular vibration.



Overview of ML process

Expected Outcomes

- Certain combinations of amplitudes and frequencies of vibration will cause more of an injury risk than others.
- Finding the combinations with the least amount of injury risk can be used to see if vehicle’s can be manufactured to have the passenger's vibration fit these combinations.
- **A method to assess risk of injury associated with vehicular vibration.**

Conclusions

- Investigating the effects of whole-body vibration on low-back pain can be important to reduce the pain in millions of people.
- Using FE simulations will give insight into whole-body vibration without having to risk injury to real subjects.

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