Analysis of Head Injury Criterion for Backyard Roller Coaster

Simon Luong, Mechanical Engineering
Mentor: Professor Steven Dobbs
Kellogg Honors College Capstone Project

Abstract

With the development of automobiles, modes of transportation, and means of entertainment in the engineering world, safety has always been the absolute priority. Although many automobile companies and private roller coaster design companies have many proprietary tabulated values for safe conditions of operation, many of these values can be quantified through numerical as well as empirical values. One issue of high priority in the scope of a homemade backyard roller coaster is the head injury possibilities under conditions of worst case failure of the attraction. Although factors of safeties as well as redundancies are designed into the attraction, measures to protect the rider from injury in case of failures must still be taken. In this safety design analysis, the head injury of the passenger is analyzed to ensure safety in the event of complete track failure at the most critical points in the attraction.

Objectives

•Given the backyard roller coaster design previously created, analyze the point of maximum:

- Velocity
- Acceleration
- Risk of Injury

•Assuming the roller coaster comes to a complete, immediate stop due to fracture of a track joint where the cart interferes with the lateral cross member at 90°, assess the susceptibility of passenger head injury

•Determine HIC value and characterize safety criterion of passenger

•Under worst case impact scenarios, are the passengers

Background

Kinematics:

$$v^2 = {v_o}^2 + 2a(\Delta x)$$
$$x = x_o + v_o t$$
$$v = v_o + at$$
$$x = x_o + v_o t + \frac{1}{2}at^2$$

HIC:

$$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,dt\right](t_2 - t_1)\right\}$$

Where:

t_1: $starting\ critical\ time$
t_2: $ending\ critical\ time$
$a(t)$: $acceleration/deceleration\ function$

From Previous Calculations:

$a_{max\ tangential} = 2.1\ g's$
$v_{max} = 11.7\ mph$

Experimental Values for HIC of Various Automobile Models	
Make and Model	**HIC Score**
1998 Ford Windstar	353
1998 Dodge Neon	655
1998 Toyota Camry	525
2007 Toyota Camry	505
1995 Audi A8	142

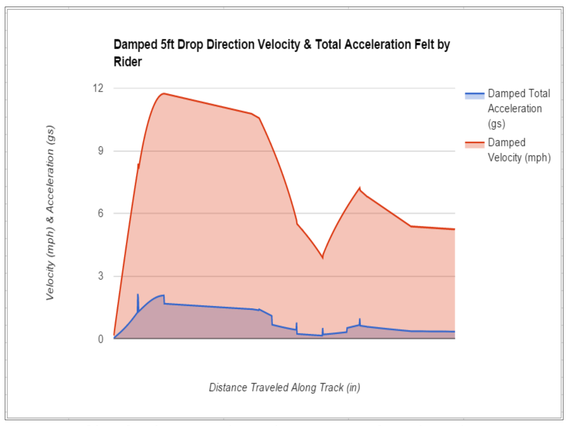
Table of various car manufacturer HIC values

Crash Dummy used for impact tests

Dummy Type	Mid-Sized Male	Small Female	6 Year Old Child	3 Year Old Child	12 Month Old Infant
Existing / Proposed HIC Limit	1000	1000	1000	900	660

Table of maximum acceptable values of HIC for various age groups

Analysis Results

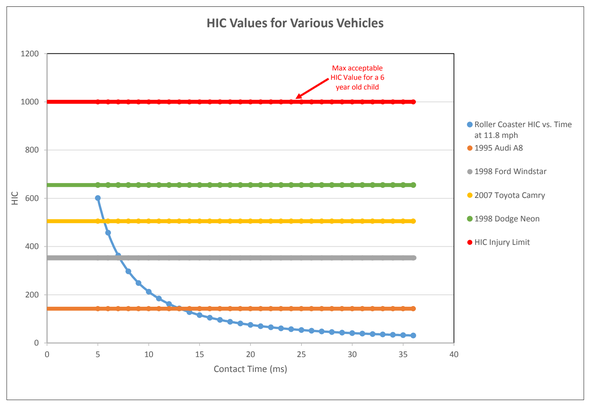


Profile of Velocity and Acceleration in 5 foot drop direction

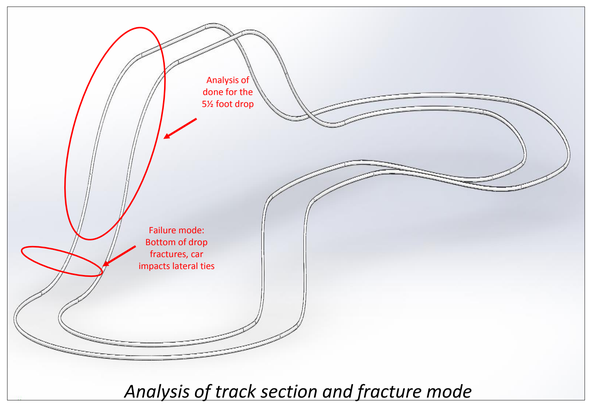
Assumptions:

- Analyzed the 5 ½ foot drop
- Max acceleration solved
  as v_o= 11.7 mph → v
  as t varies from 5ms → 36ms
- Failure mode:
  Track at the bottom of 5 ½ foot drop snaps as car comes to halt as it impacts the lateral beam holding the track in place
- Car impacts laterals at 90°

- Using values suggested by the development of improved injury criteria of contact time was suggested to be between 5ms and 36ms
- The roller coaster HIC values have been graphed against HIC values of various car models as well as the safe HIC injury limit
- All values for the 3-year-old HIC limit were kept under the maximum HIC value when analyzing the safety of the roller coaster impact
- The roller coaster safety factors are sufficiently safe for even a 12-month-old infant



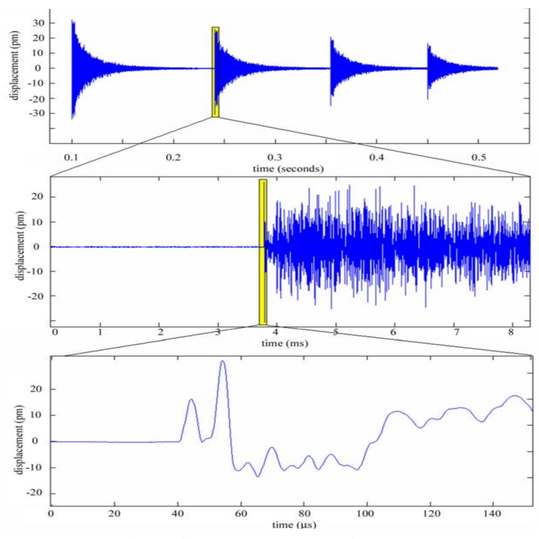
HIC values compared to typical car models



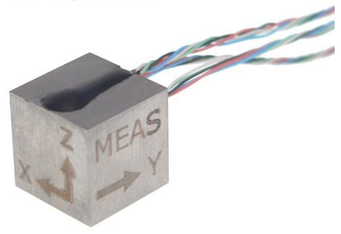
Analysis of track section and fracture mode

Discussion and Future Work

Although these calculations are done in the most severe situations, these calculations cannot always portray the most ideal or realistic situations. Values such as the contact can be experimentally tested and obtained using a pendulum setup. Using calibrated weights and lifting the pendulum to a calculated height, the correct speed and mass of the cart can be simulated. The properties of the pendulum can then be released at the specified height in order to simulate the wood on wood impact. Using accelerometers at a very high sample rate, the time of peak acceleration and critical impact can be captured.



Analysis of car contact time in the Time Domain



Accelerometer can be used to measure g's in the test

Pendulum test can be used to simulate the impact

References

- "Greg McLaskey's Webpage." *Greg McLaskey's Webpage*. N.p., n.d. Web. 11 Feb. 2016. <http://glaser.berkeley.edu/greg/impact.html>.
- "II. Injury Risk Curves and Protection Reference Values." *II. Injury Risk Curves and Protection Reference Values*. N.p., n.d. Web. 11 Feb. 2016. <http://www.nhtsa.gov/cars/rules/rulings/80g/80gii.html>.
- 162, and Teaching Mathematics And Its Applications Volume 17, No. 4, 1998. *Km M M M M* (n.d.): n. pag. Web. 11 Feb. 2016.
- "Operational Amplifier Basics - Op-amp Tutorial." *Basic Electronics Tutorials*. N.p., 22 Aug. 2013. Web. 10 Feb. 2016. <http://www.electronics-tutorials.ws/opamp/opamp_1.html>.
- "Test Protocols and Technical Information." *Technical Protocols*. N.p., n.d. Web. 11 Feb. 2016. <http://www.iihs.org/iihs/ratings/technical-information/technical-protocols>.