The Journal of Management and Engineering Integration
Vol 1, No.1, June 2008

Development of a Low-Cost Weigh-in-Motion System

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Abstract

Limiting the weight of vehicles that use a given roadway is essential to prolonging the life of the roadway pavement and can also impact safety. Enforcement of weight limitations requires some method of weighing the vehicles that are using the roadway; however, the scales that are commonly used for this purpose are costly to install. This paper reports on investigations into a low-cost weigh-in-motion (WIM) system using acoustic emission technology. Laboratory testing of the concept was conducted and verified that a correlation exists between various acoustic emission parameters and applied load (vehicle weight). Field-testing of the proposed equipment has begun and initial results are presented.

1. Introduction

In an effort to extend the useful life of roadway pavement and improve vehicle safety, weight limits have been set for heavy trucks utilizing the nation's highways. [1] To enforce the weight limits, trucks are weighed at weigh stations along the highway and overweight vehicles are ticketed and/or fined. Weigh stations take a variety of forms, including:

- traditional weigh stations where heavy vehicles are pulled off of the highway and weighed on low-speed WIM scales and/or stationary scales, and
- Remotely Operated Compliance Stations (ROCS™) where heavy vehicles are weighed at highway speeds in the travel lanes. [2-6]

Typical weigh stations collect information about axle weight, axle configuration and spacing, and whole vehicle weight. In addition to weight enforcement, this data can also be used for a variety of transportation planning purposes, including the design of pavement and bridge structures, planning transportation facilities, and safety analysis. [7]

Static scales measure the weight of a vehicle at rest. Because of the large size of the vehicles involved, the scales are usually built to weigh only one axle at a time. That is, the vehicle is parked with just the front axles on the scale and the weight is measured, then the vehicle is moved so that the second set of axles rests on the scale, and so forth. Accurate measurement relies upon level pavement around the scale and upon the elimination of other sources of error such as load shifting between measurements. [8]

WIM systems, on the other hand, measure the dynamic forces associated with a vehicle in motion passing over the scale. The accuracy of a WIM system is affected by the type of suspension system present in the vehicle being weighed, the type of pavement (flexible or rigid), and the profile of the pavement surrounding the scale. [9]

Several different technologies are currently in use in WIM systems. The bending plate WIM system consists of steel plates surrounded by rubber and connected to strain gauges. The vehicle weight is related to the strain on the plates as the vehicle crosses over them. [10] Similarly, a WIM system can be created by measuring strain in a structure (a bridge, for instance). [11]

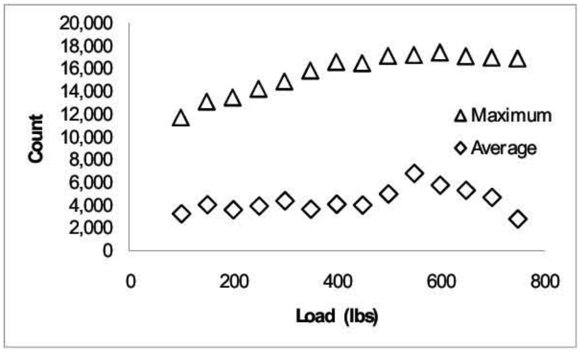


Figure 3. Count as a function of weight

Similar trends are found when energy and absolute energy are considered. Figure 4 shows a distinct trend of increased energy with increased load when the maximum hit for each TB is isolated. Figure 5 shows similar results for absolute energy.

No correlation was found between the parameters risetime, counts to peak, duration, or amplitude and load.

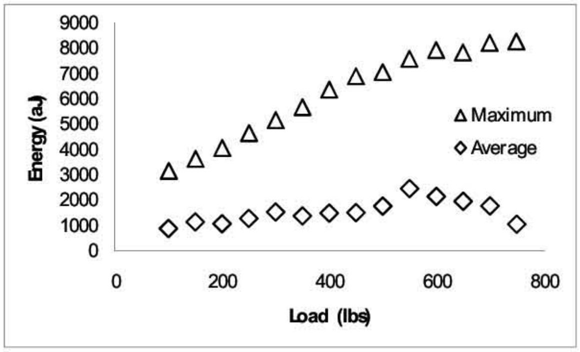


Figure 4. Energy as a function of weight

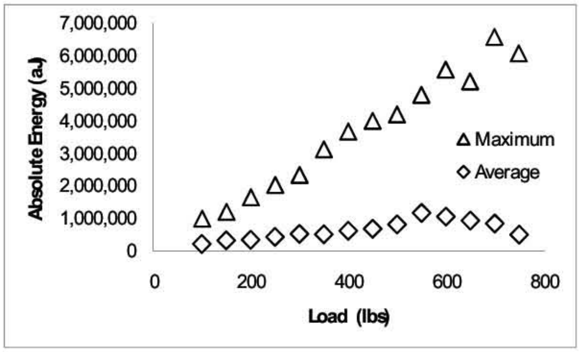


Figure 5. Absolute energy as a function of weight

7. Laboratory test results, experiment two

The second experiment focused on energy, count, and absolute energy because they were shown to be most highly correlated with load. Because the results for count, energy, and absolute energy are similar, this paper focuses on the results only in terms of energy.

An analysis was done comparing the maximum energy hit from each TB for each of the twelve settings. Energy was found to increase with load and with proximity to the sensor. Unfortunately, the variability in the data is too large to allow identification of the load based solely on the maximum energy hit in a TB. Figure 6 shows the average and standard deviation of maximum energy values for the 30 TBs at each of the 12 settings. Data points that were more than two standard deviations from the norm were deemed outliers and were not used in the calculation of average and standard deviation shown in the figure.

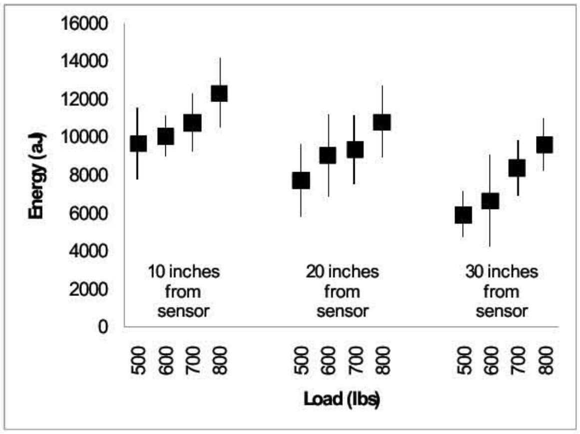


Figure 6. Maximum energy per TB

8. Field test methodology

Field (road) tests were conducted at the University of Central Florida campus. The metal strip used for this testing is long enough to extend completely across a 12 ft (3.7 m) lane, with room on either end to attach the acoustic sensors. For the first field test (experiment three), the metal strip was attached to the pavement using duct tape, with connection points every 6 inches (15 cm). Only one acoustic sensor was used. The test vehicle was a Sierra GMC truck, with a curb weight of approximately 4,000 lbs (1800 kg). The test vehicle was driven at 10 mph (16 km/h) and at 20 mph (32 km/h), under two weight conditions: empty (except for the driver) and with an additional weight of approximately 700 lbs (320 kg). Figure 7 shows the test vehicle, the computer set-up, and the metal strip taped to the roadway.

Because the road surface wasn't planar, the metal strip did not adhere firmly to the road surface and bouncing of the metal strip was observed. Since this bouncing appeared to affect the results, for the second field test (experiment four) the metal strip was firmly attached to the pavement using an epoxy glue along the length of the strip. Two acoustic sensors were used, one on each end of the test strip. The same test vehicle and speeds were used, but this time there were three weight conditions: empty, an additional weight of approximately 500 lbs (225 kg), and an additional weight of approximately 1000 lbs (450 kg). One test run was made at 30 mph (48 km/h) to determine if it was feasible to run trials at this speed; however, there was not enough distance to safely reach a speed of 30 mph and then slow down afterwards, so subsequent runs at this speed were not made.

9. Field test results

Whereas in the laboratory the relative variation in the load was large (100 lbs to 750 lbs) and the relative variation in the speed was small (2 mph to 4 mph), the opposite was true of the field tests. In the field, the relative variation of load was small (4,000 to 5,000 lbs) and the relative variation in speed was high (10 mph to 30 mph).

Consequently, in the field, correlations were found between the acoustic emission parameters and speed, but no correlations were found between any of the acoustic emission parameters and weight.

The vehicle that was used in the testing has two axles, each of which has two tires that strike the metal strip at approximately the same time. Therefore, for the field testing each strike of the metal strip is referred to as an axle bump (AB). During one repetition of the experiment, two ABs are collected, referred to as AB 1 (front axle) and AB 2 (rear axle). Figure 8 shows the typical pattern of hits collected during one repetition of the experiment. Note that the vibrations from the vehicle striking the metal strip remain for some period after the vehicle has completely passed. The time from when the vehicle first strikes the metal strip until these vibrations have died away is known as the acoustic emission duration.

Figure 7. Photo showing set up for the field testing in May 2007

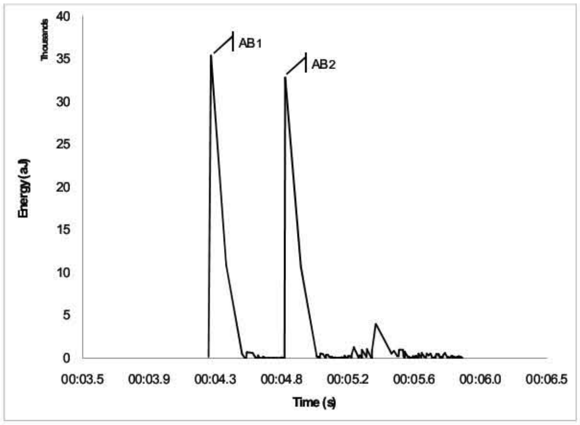


Figure 8. Typical pattern of energy in hits during one repetition (2 ABs)

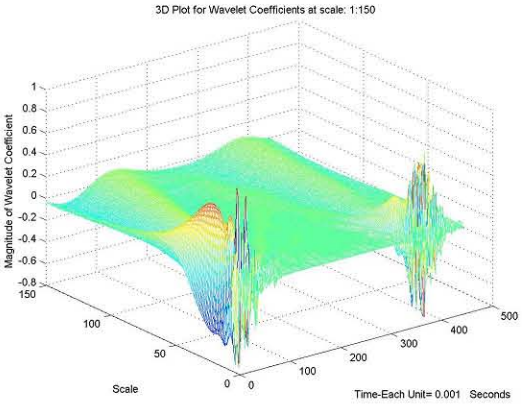


Figure 9. 3-D plot of wavelet coefficients

The speed of the truck can be computed from the time between the ABs and a knowledge of the distance between the axles [116 inches (295 cm)]. The results for different speeds are summarized in Table 1.

Table 1. Pick-up Truck Test Results

Speedometer reading (mph)	Computed speed (mph)
5	4.2
10	12.4
20	19.4
25	24.4

In addition to the acoustic emission parameters described above, the wavelet coefficient can also be determined. Figure 9 shows a 3-D plot of the wavelet coefficients. Plotting the maximum value of the wavelet coefficient for different truck speeds yields Figure 10, which clearly demonstrates the correlation between the speed of the truck (same weight) and the computed maximum wavelet coefficient.

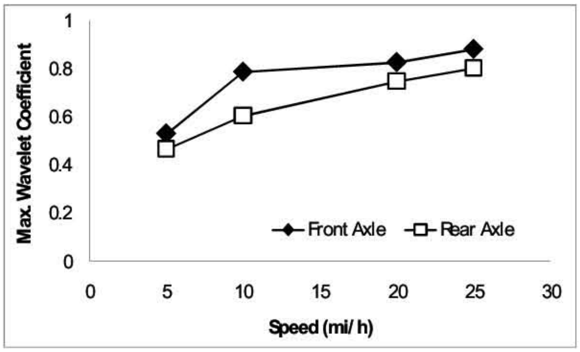
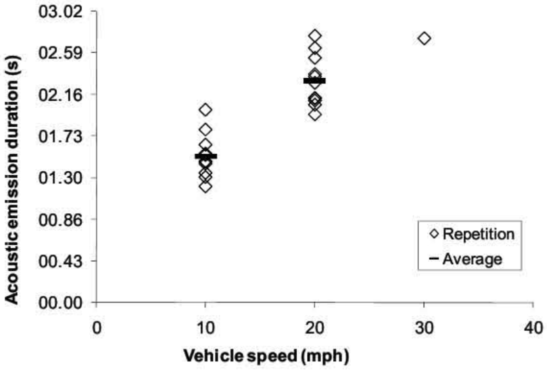


Figure 10. Correlation between maximum wavelet coefficient and truck speed

A correlation can also be made between the acoustic emission duration of each run and the speed of the vehicle. Figure 11 shows the values of these variables for each run and the averages for 10 mph (16 km/h) and for 20 mph (32 km/h).

Figure 11. Acoustic emission duration as a function of truck speed



11. Acknowledgements

This research is sponsored by the Florida Department of Transportation (contract # 16507036).

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