COMPARISON OF FUEL CONSUMPTION ON RIGID VERSUS FLEXIBLE PAVEMENTS ALONG I-95 IN FLORIDA

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Abstract

Sustainable construction and development implies investing in the needs of today without compromising the resources of future generations. The leading components of sustainability are (1) Economic; (2) Social; and (3) Environmental. Gas consumption impacts socio-economic, as well as environmental conditions. Steps to reduce fuel consumption or synonymously, increasing fuel economy are important and necessary to advance sustainable development.

An on-going study of fuel consumption by vehicles traveling on rigid (concrete) versus flexible (asphalt) pavements at Florida International University (FIU) Department of Civil and Environmental Engineering indicates that rigid pavements provide better fuel economy for the travelling public and commercial carriers. The FIU study along 28 miles of Interstate 95 in Brevard County indicates that travelers in passenger vehicles on rigid pavements use 3.4% less fuel compared to flexible pavements. These findings are consistent with research performed at Massachusetts Institute of Technology and University of Texas at Arlington.

From a socio-economic perspective, hypothetically speaking, if all pavements within the Florida State Highway System were rigid construction the annual savings in fuel consumption could be as much as 500 million gallons less and the annual savings to the public would be an estimated $2.0 billion. Environmentally, CO₂ emissions would be reduced by 5 million metric tons annually as a result of reducing fuel consumption by 500 million gallons in Florida. While these overall benefits are extrapolated estimates, the findings of this study indicate the potential for real sustainable benefits by increasing rigid pavement lane miles into agency work programs.
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Introduction – What is sustainable development?

The United States Environmental Protection Agency (EPA) defines sustainable development as meeting the needs of the current generation without compromising the ability of future generations to meet their needs. What can we do to lessen the social, economic and environmental impacts of transportation infrastructure through material selection, design and construction? Rigid pavements provide many of the sustainable qualities to pavements as compared to flexible pavements.

The relationships of the three domains impacted by transportation development overlap on many of the sustainable qualities of concrete pavements. Figure 1 shows these relationships. Some of the qualities of rigid pavements with economic benefits of sustainable development also have social and environmental benefits.

![Figure 1. Sustainability Impacts of Rigid Pavements](image)

For instance, service life of rigid pavements is estimated to be around 30 years as opposed to the estimated 17-year service life of flexible pavements. In fact, many flexible pavements require surface repairs or maintenance every five to seven years. The longer life of rigid pavements has an economic impact because it requires fewer repairs, fewer materials, fewer construction zones requiring traffic control and fewer mobilizations and employee hourly costs.

The environmental impacts of rigid pavements as a result of the longer service life are found in the reduction of the use of non-renewal materials and fuel sources for repair. This also results in lower greenhouse gas emissions from construction equipment and vehicles idling due to lane closures and reduced vehicle fuel consumption.

The social impacts of longer life pavements are realized from the elimination of construction zones that result in lost time to the public caused by lane closures and more importantly, the elimination construction zone safety hazards that may result in loss of property or life in construction zone accidents.
Vehicle Gas Consumption and Socio-Economic and Environmental Sustainability of Rigid Pavements

Higher surface stiffness and smoother surfaces have been shown to reduce fuel consumption between 3% and 17% as compared to flexible pavements. At today’s price of fuel, around $3.50 per gallon, consumers may realize a substantial savings at the gas pump. (Aredekani, 2010). “A new study by civil engineers at MIT (Massachusetts Institute of Technology) shows that using stiffer pavements on the nation’s roads could reduce vehicle fuel consumption by as much as 3 percent — a savings that could add up to 273 million barrels of crude oil per year, or $15.6 billion at today’s oil prices. This would result in an accompanying annual decrease in CO₂ emissions of 46.5 million metric tons.” (Brehm, 2012).

Research at the University of Texas at Arlington found that the difference in fuel consumption may be as large as 17% more on flexible pavements than on rigid pavements (Aredekani, 2010). Impacts, such as these, especially in highly congested urban areas, could have substantial sustainability implications in Florida and nationwide.

Florida International University On-going Study

Location of Study
Using the study at MIT as a backdrop, Florida International University (FIU), in a research partnership with MIT, commenced a study of fuel consumption difference on the Florida State Highway System. A segment of I-95 in Brevard County was selected for the study. Figure 1 shows the segments of I-95 selected for the study.
The test sections were identified as I-95 Northbound from mile marker (MM) 189 to MM 204 and I-95 Southbound from MM 204 to MM 189. Both directions of the interstate are three lanes and relatively flat with a posted speed limit of seventy miles-per-hour. The sections between MM 189 to MM 196 are flexible pavements in both directions and the sections between MM 197 and MM 204 are rigid pavements in both directions. The pavements transition between flexible and rigid between MM 196 and MM 197, in both directions. The sections provided a total of fourteen miles of data for each complete run for each pavement type. Figure 2 shows the similarity of the geometries of the test sections, with the flexible pavement in the upper photograph and the rigid pavement in the lower one.
The flexible section was rehabilitated in 2009 – 2010. The pavement structure consists of 9.25” (min) of asphalt concrete (including 0.75” of open-graded friction course), 5” (min) of limerock base and 12” of stabilized subgrade (Type B). The design AADT was 78,000 vehicles with 5.1% trucks. The current International Roughness Index (IRI) averages 48 inches/mile. Falling weight deflectometer (FWD) data are no available.

The rigid section was also rehabilitated in 2009 – 2010. The pavement structure consists of 13” plain, jointed Portland Cement Concrete, 1.0” of asphalt concrete (SP 9.5), and 4.0” of asphalt treated permeable base. The design AADT was 78,000 vehicles with 5.1% trucks. The current IRI is 46 inches/mile. Falling weight deflectometer (FWD) data are no available.

Results from the Florida Department of Transportation (FDOT) Annual Pavement Condition Survey indicate that both sections were completed within the last two years and the existing International Roughness Indices are similar with averages approximately fifty inches-per-mile. The test plan was to select days and times where traffic volumes were to be light to moderate so that the cruise control on the test vehicle could be set and maintained throughout the full fifteen-mile run in each direction without changing lanes or accelerating. After a run in the northerly direction the driver changed to the southern direction at the nearest exit. Once in the southerly direction the speed control on the vehicle was reset prior to reaching the beginning mile marker and maintained throughout the southerly run.

The purpose of this exercise was to eliminate variables that may affect fuel consumption other than the pavement surface. One variable that was introduced into the study is overall direction of the highway and wind velocity. The flexible section from MM 189 to 196 runs mainly north-northwesterly on the northbound side and south-southeasterly on the southbound side. The rigid section, from MM 197 to MM 204 runs mainly northwesterly on the northbound side and southeasterly on the southbound side. The uncontrollable effect of wind velocity (speed and direction), therefore, had an effect on results and will be discussed later in this report.

**Vehicle Used in Study**

The vehicle used in the study was a 2011 Hyundai Genesis sedan (3.8-L/V6) with a curb weight of approximately 3750 lbs. A photo of a similar vehicle is shown in Figure 3. The Genesis was considered an average-size vehicle to represent a large cross-section of currently used passenger cars.
Data Collection Instrumentation
Actual instantaneous gas consumption was accomplished using the On-Board Data (OBD) collection capability of the vehicles. Modern vehicles generate a large amount of operational data that is used by manufacturers to diagnose problems and monitor vehicle operational performance. The OBD port on the 2011 Hyundai Genesis is located under the driver-side dashboard. A commercial OBD collection device was used to upload the desired data into a computer (laptop) database in real time. Figure 4 shows the OBD device used to connect to the vehicle’s OBD port and the USB port of a laptop computer.

The instantaneous gas consumption and vehicle speed were uploaded in real time to a Dell laptop computer. The data are entered into an Excel Spreadsheet database format for analysis at a later time. Figure 5 shows the data collection in real time on the laptop screen.
Figure 5. Real-time Data Collection of Instantaneous Fuel Consumption and Vehicle Speed.

Test Results / Observations
Once data collection was complete, the data were reduced to average fuel consumption in both directions for each of the pavement types. Overall fuel consumption averages for each pavement type were determined to adjust for wind velocity and to obtain an average over the fourteen miles of data for the rigid pavement and the fourteen miles of data for the flexible pavement. Examples of raw data displayed graphically are shown in Figures 6 and 7. Data were collected at a rate of four readings per second.
The troughs and spikes are changes in fuel consumption on overpasses along the highway sections. The overpass on the flexible section is located at MM 192. The overpasses on the rigid section were located at MM 201 and MM 202. The affect on the average fuel consumption on the rigid section, which includes the two overpasses, was less than five one-hundredths of a mile-per-gallon. Because the
overall effect was small in relation to all data collected, these data from the overpasses were included in the analysis.

The averages of data collected on the first day of testing are shown by the bar graph in Figure 8. Several observations may be made from this bar graph. First, wind velocity (speed and direction) have a substantial effect on fuel consumption. Note that the wind velocity is eleven miles per hour out of the northwest. Because these two sections run in a basically southeast to northwest direction, the net effect on the rigid pavement section is a difference in wind magnitude of twenty-two miles per hour.

There was an eleven mile per hour headwind traveling northbound and an eleven mile per hour tailwind traveling in the southbound direction. The average overall difference between the two directions for the rigid pavement is 4.6 miles per gallon. Because the flexible sections run primarily in a north-northwest direction, the effect of wind was some vector component of the actual wind speed and the effects are smaller in magnitude than on the rigid sections, but still substantial. The average difference in fuel consumption along the flexible pavement sections were 3.4 miles per gallon.

A second observation is whether the vehicles were traveling into a headwind or with a tailwind, the rigid pavement provided more economical gas mileage. With a tailwind, the vehicle traveling on the rigid pavement achieved a higher fuel economy of 2.1 miles per gallon over the flexible pavement. With a headwind, the vehicle traveling on the rigid pavement achieved a higher fuel economy of 0.9 miles per gallon.
The third observation is the overall averages of each pavement type in both directions indicate that the rigid pavement section provided a greater fuel economy by 1.5 miles per gallon over the flexible sections. Therefore, the rigid pavement used 4.6% less fuel than the flexible pavement over four sets of data.

Findings

Similar sets of data were collected in December 2012 and January 2013 in order to increase the database for more reliable observations and to normalize the effect of wind velocity on fuel consumption for both pavement types. Figure 9 is a bar graph showing the overall averages of each day of data collection for each pavement type along with the overall averages of all days of data collection for each pavement type.

Figure 9. Miles per Gallon Comparative Data
This graph shows the averages of each day of data collection (one day per month for three consecutive months) along with the overall averages and average differences for all data collected. The information along the horizontal axis provides information about the date the data were collected and wind velocity. The average IRI for both sections were equivalent at 46 inches per mile for the rigid section and 48 inches per mile for the flexible sections. The ambient temperature range was 49 to 78 degrees Fahrenheit. The overall average of fuel consumption for all data collected for the flexible sections is
31.4 mpg while the overall average of fuel consumption for all data collected for the rigid sections is 32.5 mpg.

The mpg data were converted to fuel consumption in gallons per 100 miles (gphm) in order to conform to research findings previously published by the Concrete Sustainability Hub at Massachusetts Institute of Technology. Figure 10 is a graph of the comparative gphm data.

**Figure 10. Comparison of Fuel Consumption of Rigid versus Flexible Pavement**

On the average, the rigid pavement yielded a fuel economy 3.4% better than the flexible pavement.
Discussion

According to the 2010 report from the Florida Department of Revenue, approximately 15.3 Billion gallons of vehicle fuel were consumed in Florida (1.4 billion gallons of diesel, 8.2 billion gallons of gasoline, 5.7 billion gallons of gasohol). (2010 Florida Motor Gasoline and Diesel Fuel Report, August 2011) Using data collected by Florida International University Department of Civil and Environmental Engineering, all else being equal, traveling on rigid pavements consumes 3.4% less fuel than traveling on flexible pavements. If all pavements in Florida were rigid, this could theoretically amount to an annual fuel savings of nearly 500 million gallons of fuel and an estimated $2.0 billion savings to the highway users (using an average fuel cost of $3.50 per gallon). An interesting analogy would be that for every twenty-five days of commuting to work, the commuter would realized on nearly free day of fuel if able to commute on rigid versus flexible pavements, regardless of the length of the commute.

From an environmental perspective, using estimates from the United States Environmental Protection Agency of 0.00892 metric tons of CO₂ emitted per gallon of gasoline consumed, traveling exclusively on rigid pavements could reduce CO₂ emissions by as much as 5.0 million metric tons annually. (Agency). The impact on the environment is as astonishing as the economic impact to the traveling public. This is especially critical in urban areas such as Miami, Orlando, Tampa and Jacksonville where large numbers of vehicles operate in highly congested areas on a daily basis.

Utilizing rigid pavements in express and premium lanes could contribute to increased usage as the cost of the toll may be somewhat offset by the savings in fuel consumption, depending on the toll charged at the time of use. At any rate, the fuel savings could have a substantial positive impact on fuel costs and greenhouse gas emissions. Both factors could be used on life cycle cost analyses in pavement type selections.
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