Extracting Tire Model Parameters From Test Data

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ABSTRACT

Computer models used to study crashes require data describing the vehicles. Data such as weight, length, wheelbase, tire locations, crush stiffness, tire parameters, etc. all require some source of information. Usually the tire parameters are difficult to obtain and analysts will routinely use default or “typical” values. Engineering Dynamics Corp. (EDC), with support from many in the field of crash reconstruction, conducted a tire test series in 1999 to obtain tire data that will be used in studying motor vehicle performance. The computer simulations in use today require some type of tire data coefficients or lookup tables that must be extracted from the raw collected data. This paper presents a basic overview of the tire test data and presents a technique for extracting the required tire parameters for use in computer simulation modeling.

INTRODUCTION

The use of computer simulations to study motor vehicle collisions has required significant data gathering efforts over the years. Approximately 15 years ago the vast majority of crash reconstructions involved grouping vehicles into categories. Eventually, analysts realized that vehicle stiffness coefficients for each specific vehicle produced results that were closer to real-world data. Now it is considered standard to get the best stiffness data you can for each vehicle involved, even though it really may not make much difference in the level of detail for a given analysis.

Improvements in data sources for other vehicle parameters have also taken place. Sources of data or “rule of thumb” equations for vehicle dimensions, weights, moments of inertia, center of gravity location, etc. are available for most vehicles today.

One area where data sources have not been developed is for tire data. Depending on the simulation model being used, the required data varies from single coefficient of friction and cornering stiffness values up to detailed lateral force vs slip angle (Fy vs Slip), longitudinal force vs slip% (Fx vs Slip%), radial stiffness, etc. The data that are available currently are based on tire testing conducted almost 20 years ago.[1]

In most cases, tires from the same size and construction type behave similarly from one model and manufacturer to another. Consider that when replacing a tire on a typical passenger car we typically are not concerned with anything other than size and construction type. Thus it is with computer simulations, using generic data is probably okay for most situations. However, in some instances more specific data may result in a more accurate reconstruction. The fact is we do not really know the effect of using more detailed tire data, it is simply an assumption that it will not really make much difference in most cases. However, the actual comparison studies have not been done, partly due to the fact that very little detailed tire data is available publicly.

Approximately two years ago (1999) Engineering Dynamics Corp. in Beaverton, OR put together a series of tire tests.[2] The data were recorded and reported in printed and digital form to all those who participated in the testing by purchasing a tire and then paying a portion of the test fees. In order to use this data, the tire model parameters need to be extracted from the raw data.

This paper presents the basic techniques for extracting the tire parameters used in the HVE (Human Vehicle Environment) tire models.

TIRE TESTS

The tire data being discussed in this paper was all collected at Calspan Corporation during the EDC tire testing week in January of 1999. Any tire test data from other sources should work with the same basic algorithm discussed herein, however caution should be used to ensure the testing techniques and data gathered are similar.

Tire testing is a long, boring process. There are seldom any failures of a tire (to add some excitement) and once you have seen one tire test film you will probably fast-forward through any others you watch to just make sure nothing exciting happens.

However, the test process is very important and needs to be understood to fully appreciate the data being collected and how to extract the parameters needed.

In these tests, the data recorded included:

Time (sec)
Speed (mph)
Slip% - referred to as SL
Slip Angle (degrees)
Inclination Angle (degrees)
Load - Fz (lbs)
Longitudinal force - Fx (lbs)
Lateral force - Fy (lbs)
X Moment - Mx (ft-lbs)
Y Moment - My (ft-lbs)
Tire pressure (psi)
Rotation speed - N (rpm)
Temperature (degF)
Loaded Radius - RL (in)
Effective Radius - RE (in)
Normalized Fy - NFy
Nomalized Fx - NFx

There are two test procedures involved: the first is to use various speed / load combinations (2 speeds and 3 loads) and sweep through a slip angle range of +/- 15 degrees at zero inclination (camber angle) and then vary the inclination angle to 3 degrees and repeat the tests; the second procedure is to use a single speed with various loads (3 loads) and apply braking to take the tire up to approximately 50% slip.

When two speeds were used, they were 30 mph and 60 mph. Tests with a single speed used 30 mph. The three loads used were the rated load, 50% of rated load, and 120% of rated load.

Slip Angle Tests

The basic procedure used in the slip angle tests was:

Condition the tire to break it in and ensure the tire has been exercised through the working range by running the tire at 60 mph for 5 minutes and then working through the slip angle range and load range to warm up the tire.

Inclination (camber) angle of 0 degrees:

Use the heaviest load (120% of rated load) and 60 mph, rotate the tire about the vertical axis to produce a slip angle from -3 degrees to +15 degrees, then to a slip angle of -15 degrees, and then to +2 degrees; at a speed of 2 degrees / second.

Decrease the load to the rated load , staying at 60 mph, rotate the tire about the vertical axis to produce a slip angle from -3 degrees to +15 degrees, then to a slip angle of -15 degrees, and then to +2 degrees; at a speed of 2 degrees / second.

Decrease the load to the lightest load (50% of the rated load) , staying at 60 mph, rotate the tire about the vertical axis to produce a slip angle from -3 degrees to +15 degrees, then to a slip angle of -15 degrees, and then to +2 degrees; at a speed of 2 degrees / second.

Increase the inclination angle to 3 degrees and repeat the above test sequence.

Finally, decrease the speed to 30 mph and repeat the above tests for inclination angles of 0 and 3 degrees.
The time-based data for slip angle, load, inclination angle, and speed is shown in Figure 1. Note the conditioning data up to about 360 seconds (6 minutes). There were approximately 4000 to 5000 data samples taken for each tire in this series of tests.

<u>Braking Tests</u>

The braking tests were conducted differently, the basic procedure for the braking tests was:

Condition the tire by running it at 30 mph for 5 minutes, then exercising the tire two times.

Start at the lightest load (50% of rated load) apply brake torque to the tire so that it begins to slip. Continue the torque application up to the point of approximately 50% slip. Then release the tire to allow it to free roll again.

Increase the load to the rated load and repeat the torque application procedure.

Increase the load to 120% of rated load and repeat the torque application procedure.

Repeat the process for three separate loads. Each time applying torque to achieve approximately 50% slip.

Repeat the process for the lightest load (50% of rated load).

In all there are three (3) sets of data for the lightest load, 2 sets for the rated load , and 2 sets of data for the heaviest load, as shown in Figure 2. There were approximately 1000 to 1500 data samples taken in this series of tests.

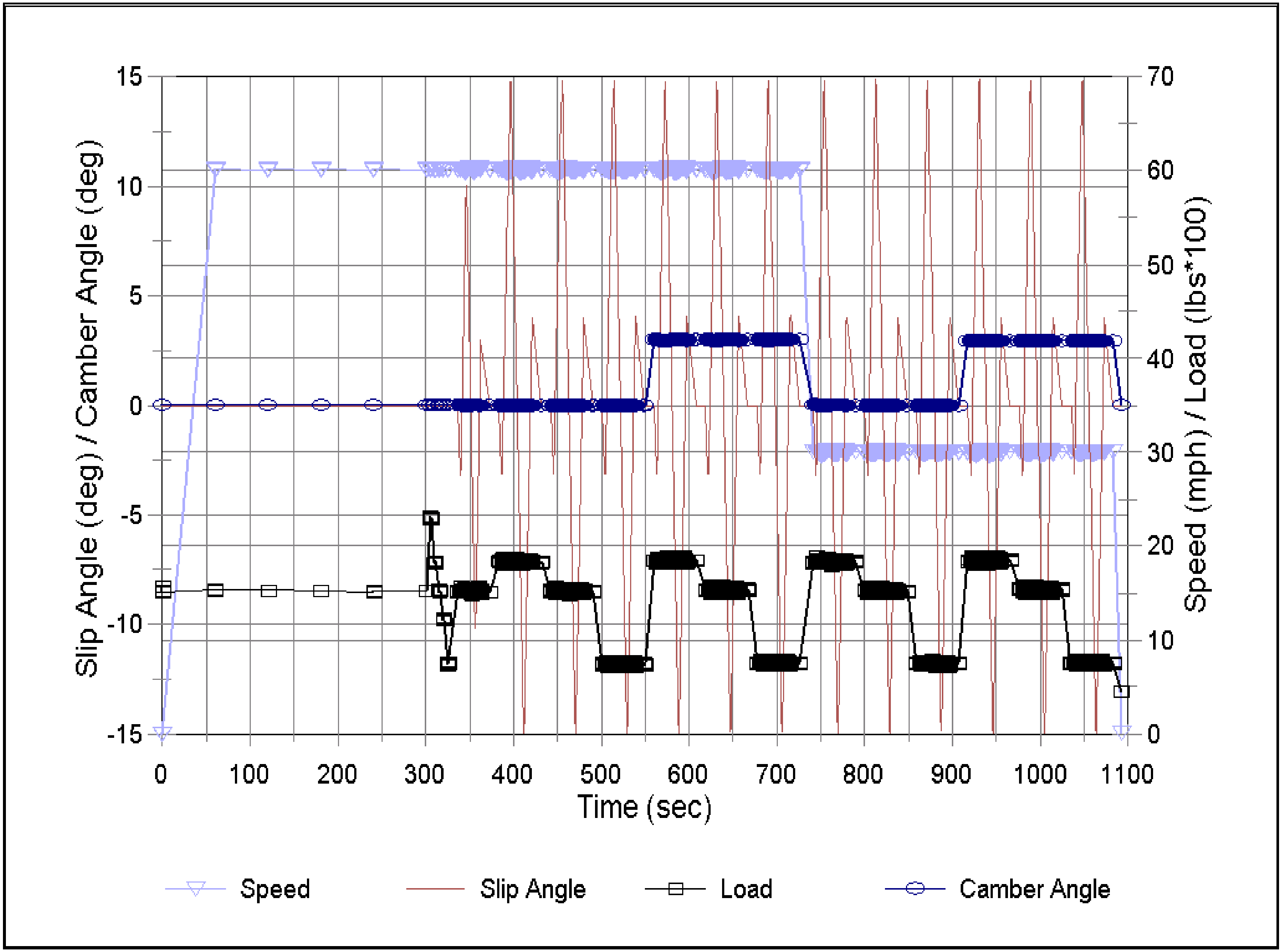

Figure 1 - Example of slip angle test data time line.

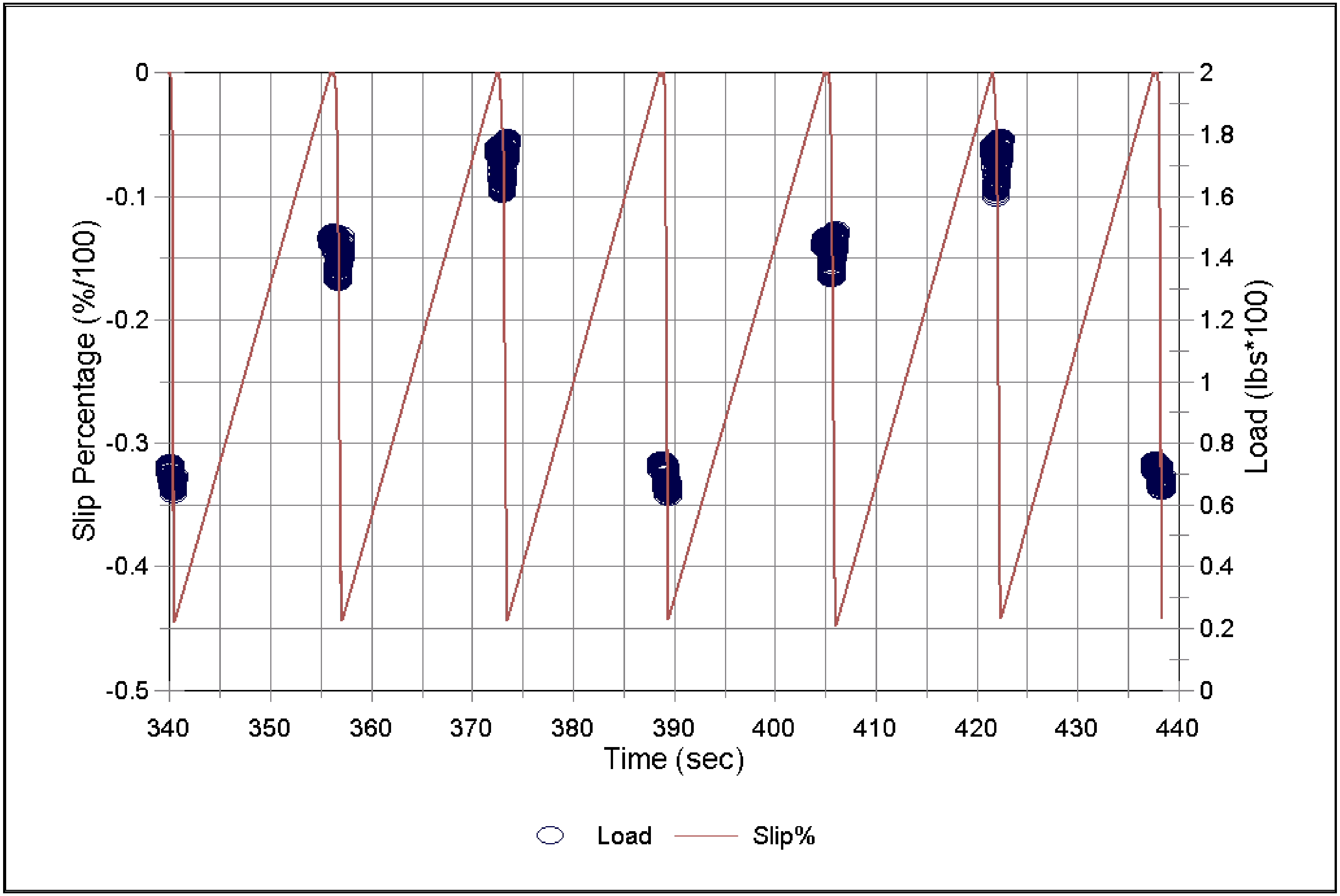

Figure 2 - Example of braking test time line.

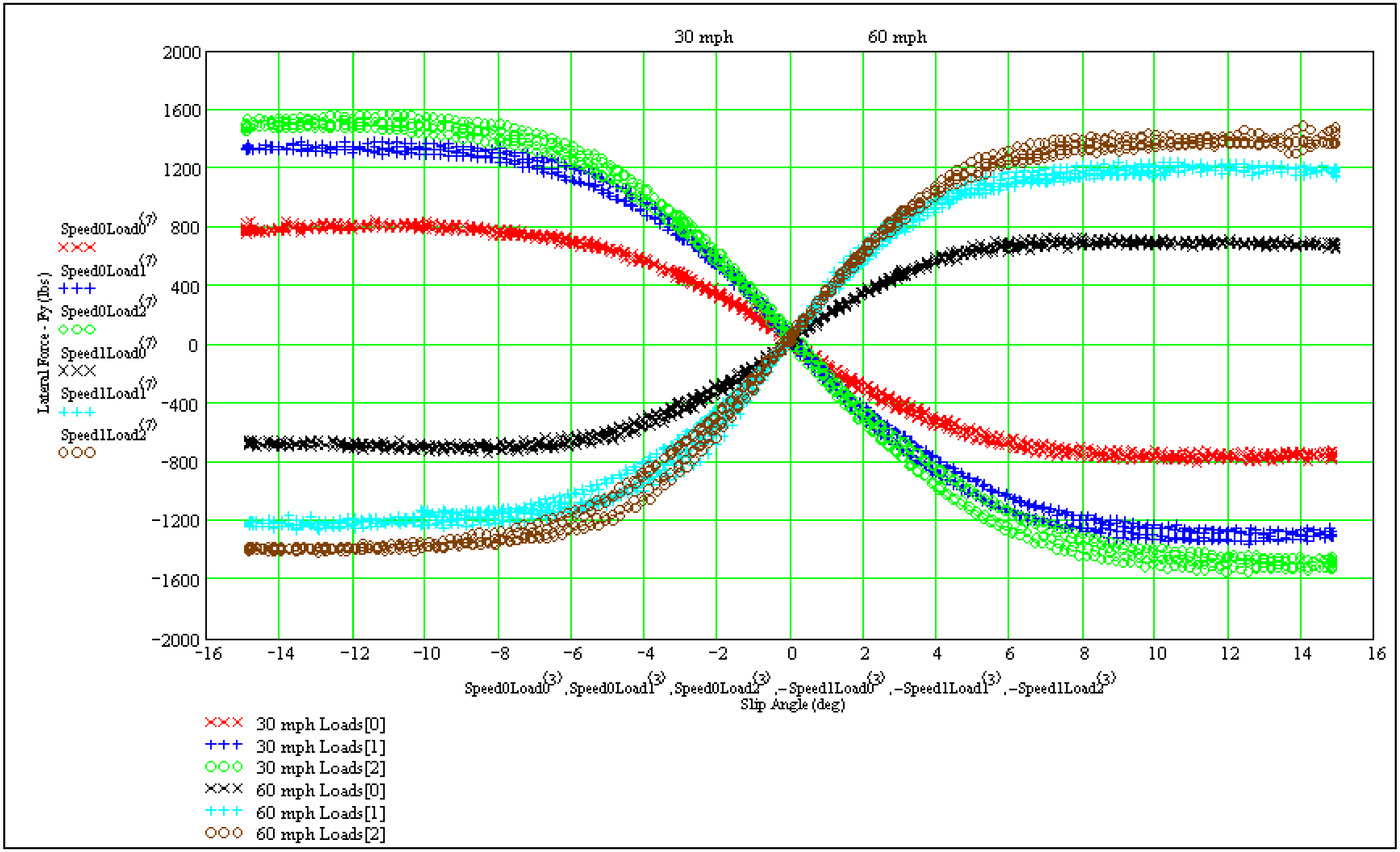

Figure 3 - Typical Fy vs SA data collected.

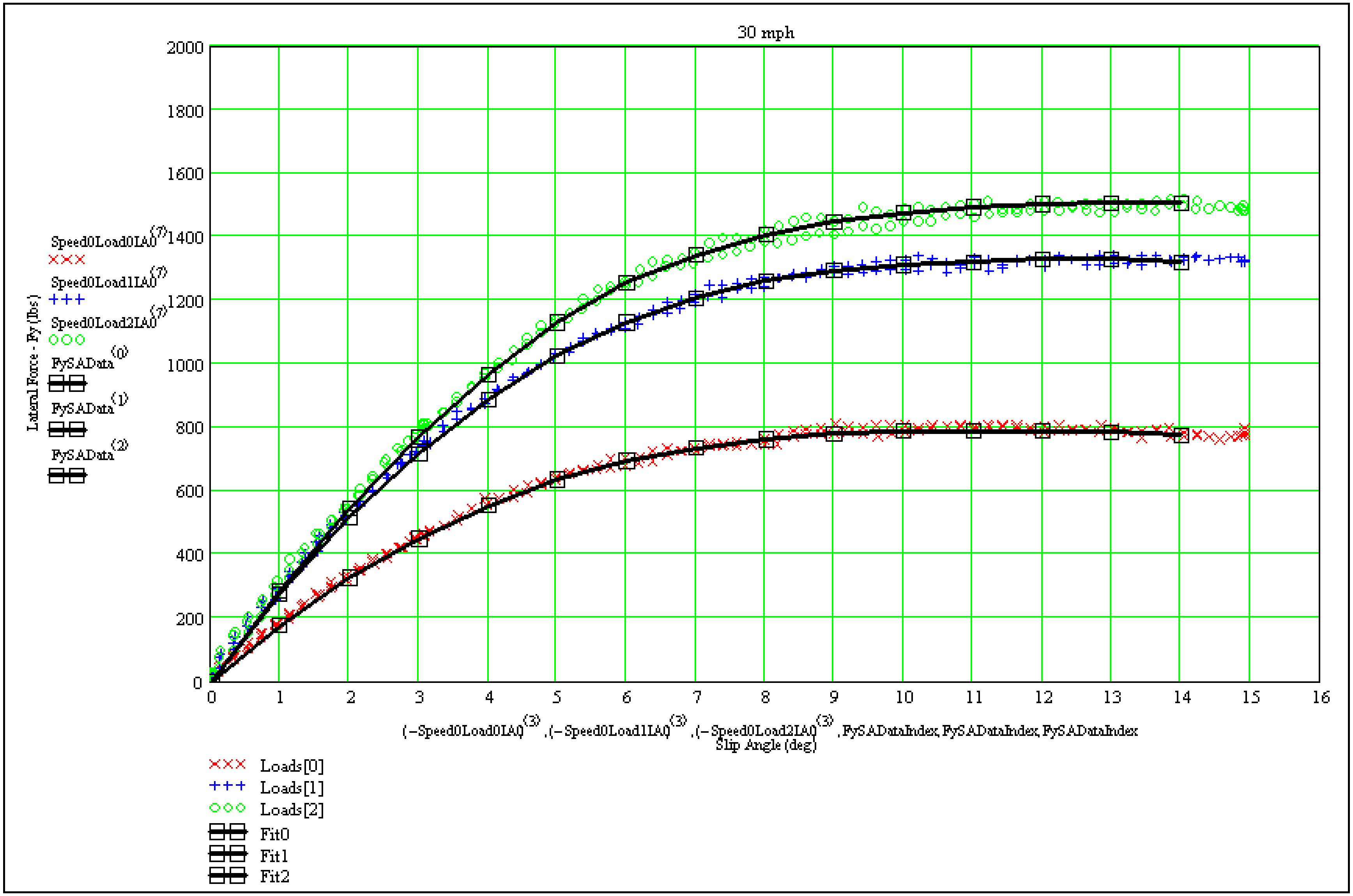

Figure 4 - Fy vs SA extracted data.

EXTRACTING THE TIRE PARAMETERS

Slip Angle Data

The first task in analyzing the slip angle data is to separate it out into groups, based on speed, load, and inclination (camber) angle. This is done by going through all the data and categorizing the data based on speed (30 or 60 mph) +/- 1 mph, load (50%, 100%, 120% of rated load) +/- 9% of rated load, and camber angle (0 or 3 degrees) +/- 0.1 degree.

The reason for +/- 9% on the rated load is to include as much data as possible without crossing over from one test to the other. If a higher value was used, for example 10%, then it is possible that some of the 120% load data would end up in the 100% load category or vice versa as they are only 20% apart and with roundoff occurring there is a possibility of crossover.

Tire model parameters in HVE are based on speed / load combinations. One typical characteristic of test data is that it will seldom be at exactly the target point, there is almost always some variation. In this case the speed may be targeted for 30 mph, but only about 1/4 of the data is at 30 mph. Therefore, ranges of values are used to include as much data as possible.

It is not obvious how to “correct” the data for samples that are not exactly at the specified speed. It is clear that the tire parameters vary with speed, but it seems that this variation is small over a range of about 5 mph or so. Therefore, no “correction” is applied to the data due to speed variations in the tests.

Load dependancy is more straightforward than speed dependancy. There is definitely a variation in tire characteristics based on load applied. However, it seems reasonable that this variation is approximately linear and proportional over a small range. Making this assumption, the test data is scaled to the correct load. First the target load is divided by the actual load, then the longitudinal and lateral force data is scaled by this value. For example, if the target load is 700 lbs., and the actual load is 650 lbs., then the lateral and longitudinal force data are scaled by 700/650 or 1.077.

There is no effort to adjust the data for variations in the camber angle data.

Once this “load correction” is applied, the data was used to calculate cornering stiffness.

Cornering stiffness is the slope of the lateral force (Fy) vs slip angle (SA) curve at zero slip angle. It is obviously not possible to calculate the slope value as this limit goes to zero, because there would not be any range of slip angle data to calculate with. Examining the graph in Figure 3, it appears that the data are essentially linear over a range of +/- 2 to 3 degrees slip angle. In this calculation, a range of +/- 1 degree of slip angle is used. A narrow range of data is extracted from the Fy vs SA curve, then it is averaged between positive and negative slip angles (assuming tire symmetry). Using linear regression the slope is calculated, resulting in the cornering stiffness coefficient for the tire at each speed / load combination.

A data table of Fy vs SA is calculated by fitting a smoothing curve through the data and then using interpolation to extract the value of Fy for each specific SA. This calculation produces Fy (lateral force) data for a specific slip angle that can then be used in the HVE tire database. This data is calculated for each speed / load combination and is shown in Figure 4 for 30 mph. The HVE dialog box for cornering stiffness and Fy vs SA is shown in Figure 5.

Camber stiffness is the slope of the camber (inclination) angle vs lateral force curve, measured at zero slip angle. There is a camber stiffness coefficient for each load / speed combination. The procedure is to extract the lateral force (Fy) for zero slip angle at zero camber and then at 3 degrees. Similar to the discussion above, a narrow range of data around 0 and 3 degrees camber angle and around 0 slip angle are used in these calculations. The camber stiffness curves are shown in Figure 6.

The peak lateral force at zero slip angle is also determined at this time. This value is used to calculate the peak lateral coefficient of friction.

Brake Test Data

Brake test data were categorized based on tire load by extracting the data into groups of light load (50% rated), medium load (rated load), and heavy load (120% rated), using the same range of +/- 9% just as was done with the slip angle data. Longitudinal and lateral forces were scaled using the tire load, similar to the technique described for slip angle data.

The HVE dialog box for friction vs slip% is shown in Figure 7, these are the parameters needed. A graph of typical braking test data is shown in Figure 8.

The first parameter determined is the longitudinal stiffness. Longitudinal stiffness is the slope of the Longitudinal force vs %slip at %slip of 0. A narrow range of %slip was used to extract the longitudinal force (Fx) near 0% extracted and the slope is calculated.

Next, the data are normalized using tire load (Fz) to calculate the coefficient of friction (Mu) vs %slip. The normalized data for a typical test series is shown in Figure 9.

The Mu vs %slip data are then fit with a spline. The peak Mu is extracted by interpolation techniques. The slide friction is calculated by fitting a linear regression line from peak friction to 50% slip, then extrapolating out to 100% slip.

Unfortunately, the data extraction for braking data has not been completed. Data up to about MuPeak has been fairly well behaved, but the data from MuPeak to MuSlide(100%) has not been as easy to extract. Additional work to extract the braking parameters for MuSlide needs to be completed.

CONCLUSIONS

Extracting tire parameters from test data is clearly feasible. Additional work needs to be accomplished on the brake data to extract the values from Peak Friction (MuPeak) to Slide Friction (MuSlide).

REFERENCES

1. Tapia, G.A. , “Extended Tire Testing”, Calspan Report No. 6871-V-1,Calspan Corporation, Buffalo, NY, 1983.

2. “Flat Bed Tire Test Data”, EDC Library Reference No. 1076 , Engineering Dynamics Corporation, Beaverton, OR, 1999.

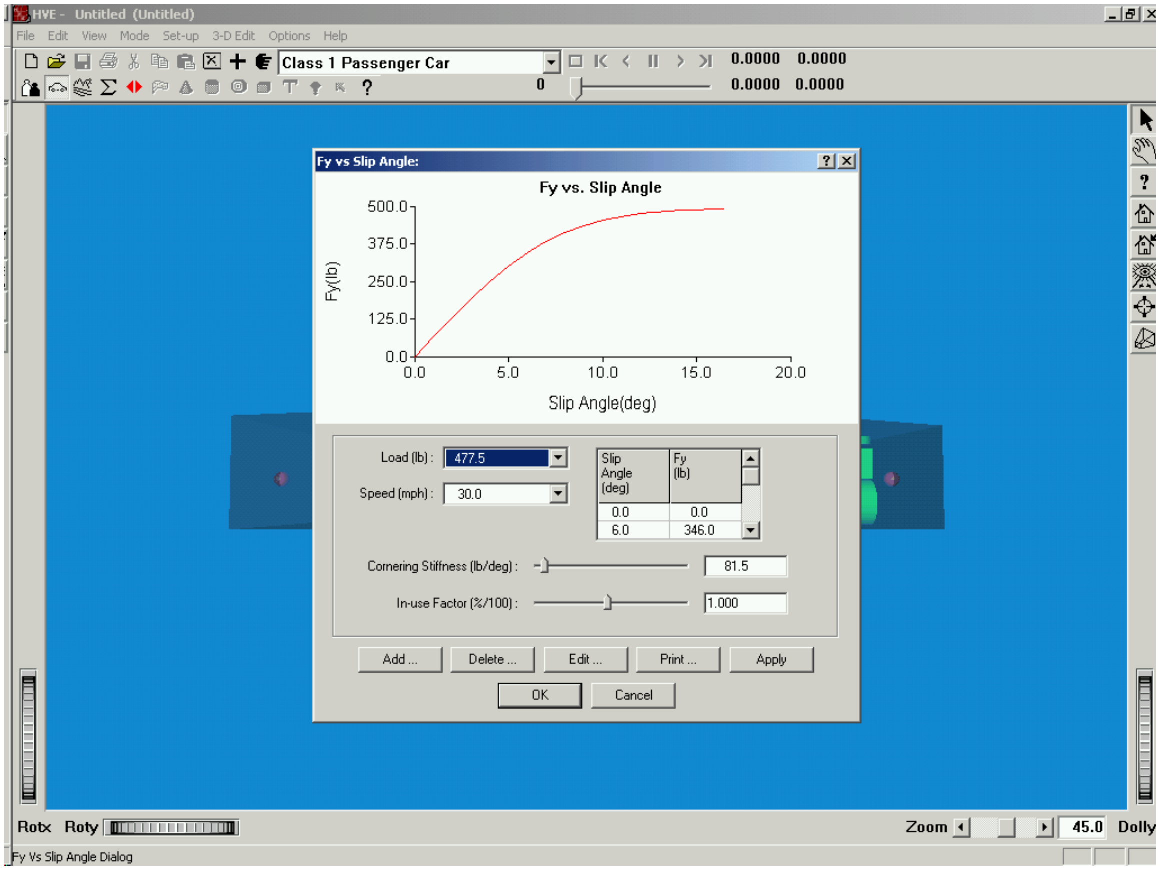

Figure 5 - Fy vs SA dialog in HVE.

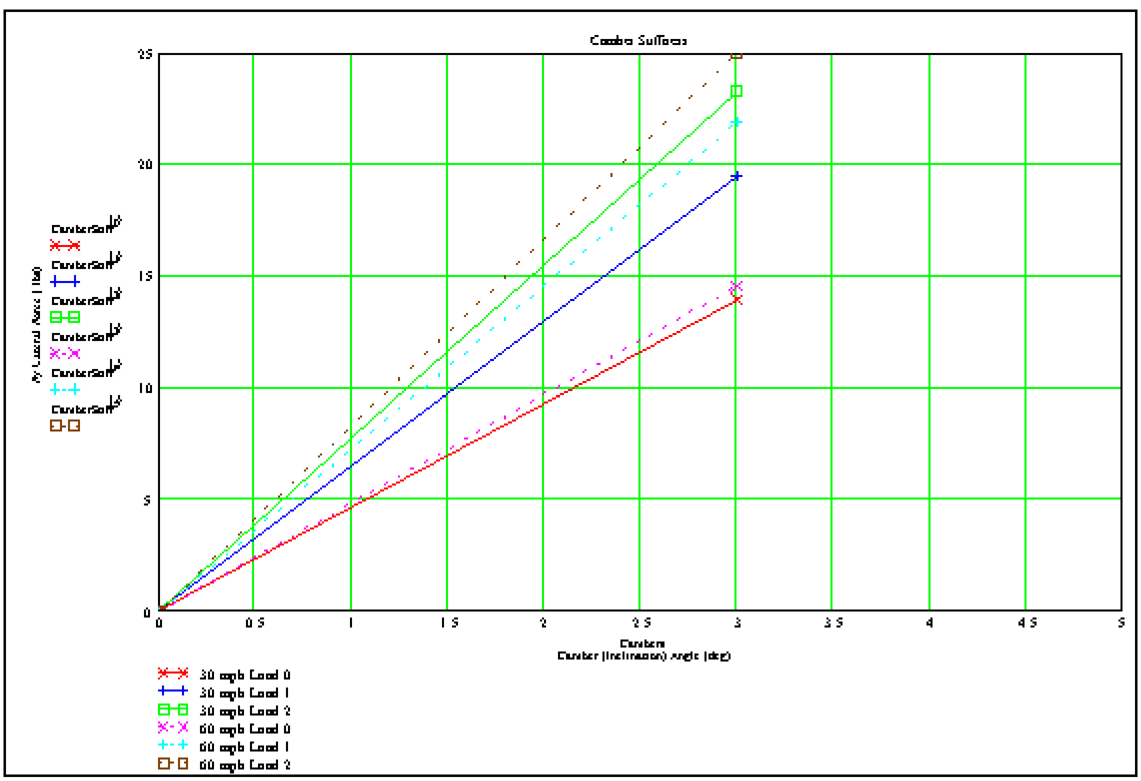

Figure 6 - Camber stiffness curves.

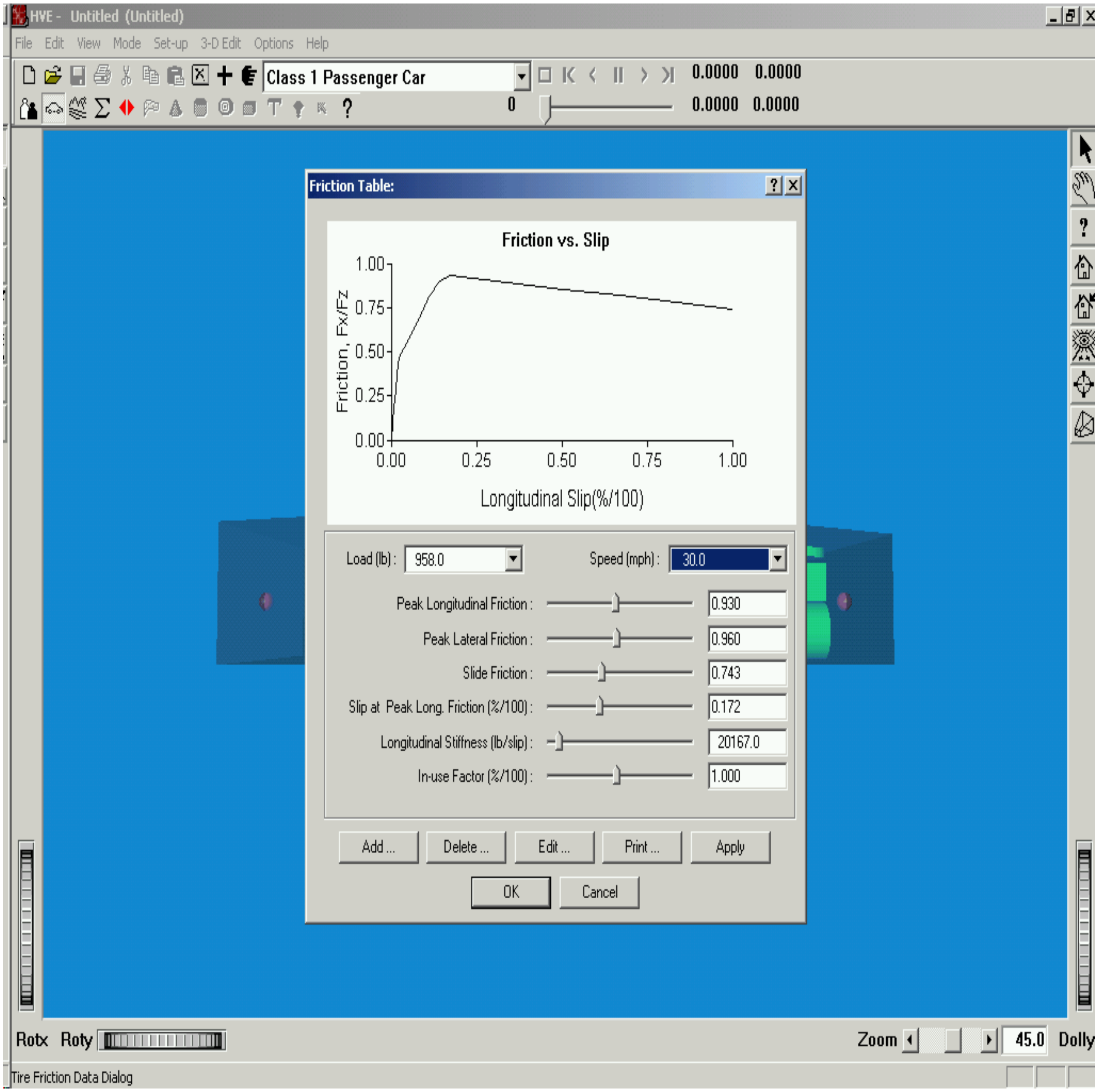

Figure 7 - Friction vs slip dialog box in HVE.

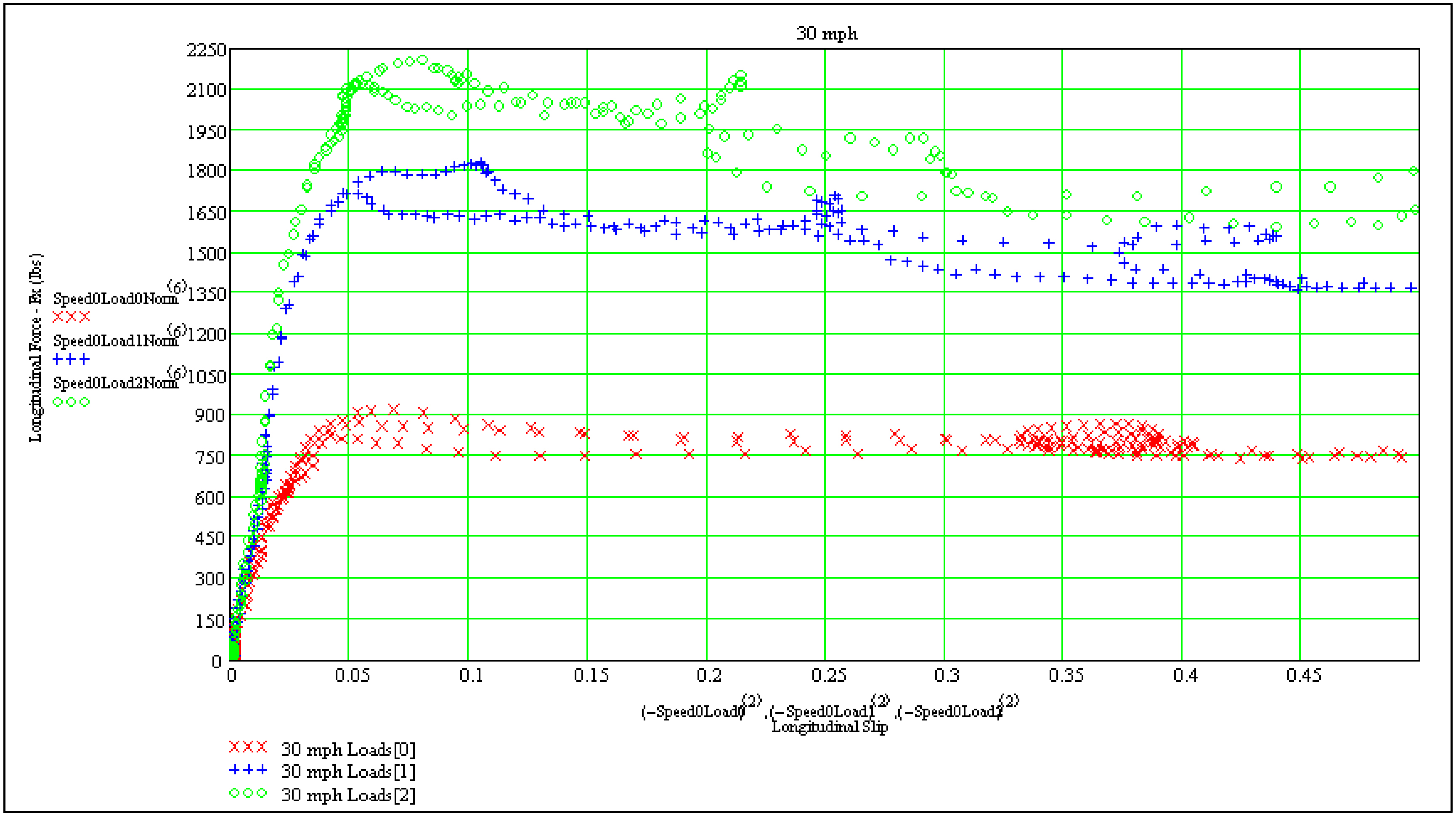

Figure 8 - Typical braking test data.

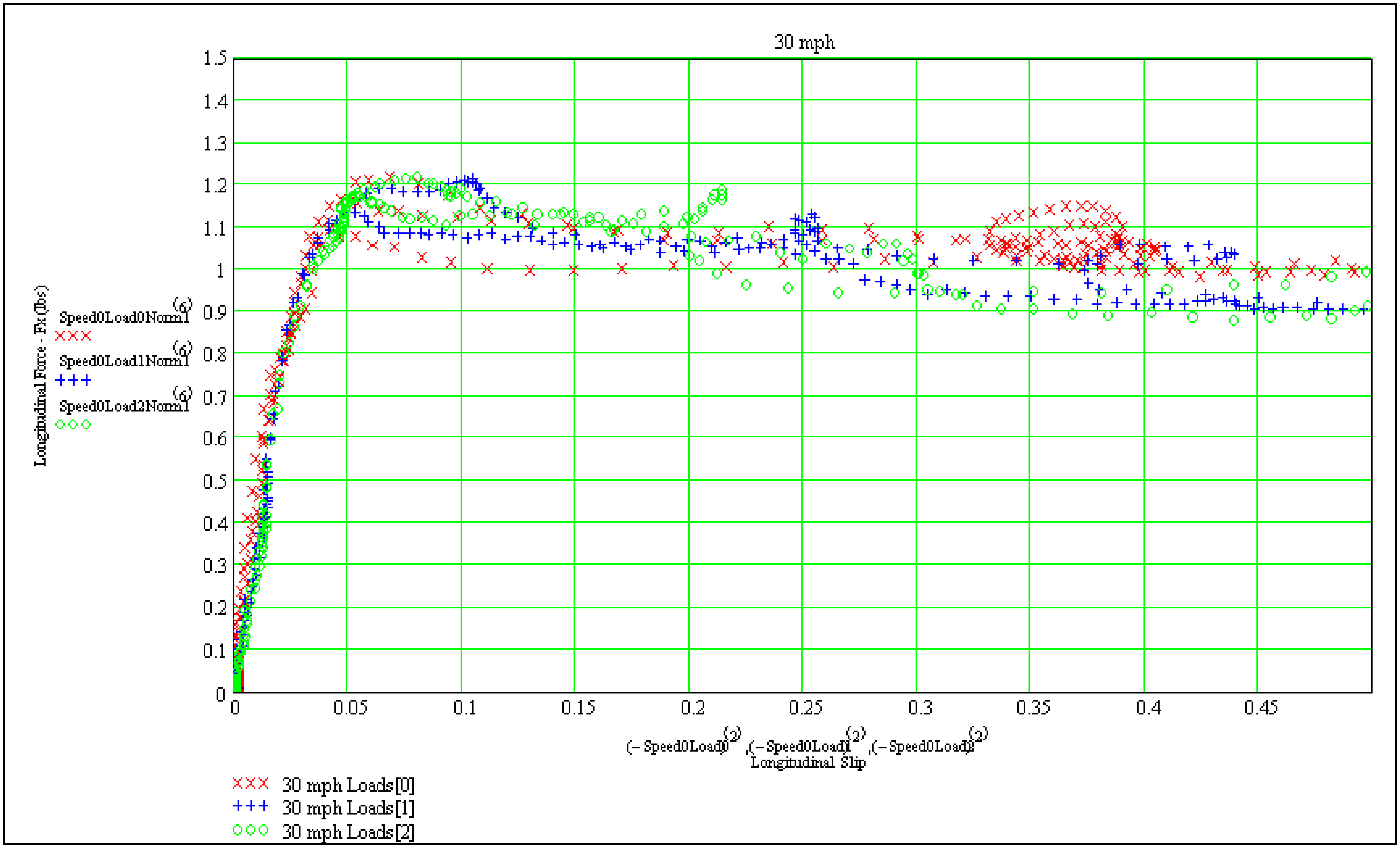

Figure 9 - Normalized data (Mu) vs %slip.