DETERMINATION OF VEHICLE COMPONENTS FATIGUE LIFE BASED ON FEA METHOD AND EXPERIMENTAL ANALYSIS

Arif Senol SENER[1]

Head of Automotive Technology Division , Vocational High Schools, Istanbul Aydin University, 34688
İstanbul,Turkey E-mail: arifsenolsener@aydin.edu.tr

ABSTRACT

In this study, construction and standardization of a track for performing fatigue and reliability test of light commercial vehicles is described. For the design and process verification of the company's vehicles one test track is defined. A questionnaire was used to determine the average usage of light commercial vehicles in Turkey. Fatigue characteristics of Turkish roads were determined by analyzing fifty different roads and this article focuses on defining the load spectrum and equivalent fatigue damage of the leaf spring resulting from the accelerated test route. Fatigue analysis and estimated lifespan of the part were calculated using Finite Element Analyses and verified by the Palmgren-Miner rule. When the customer profile is taken into consideration; Turkish customer automotive usage profile, the aim of usage of this kind of vehicle (LCV), fatigue characteristics of Turkish roads for this vehicle were determined and around Bursa one accelerated test tracks were formed for the reliability and fatigue test for the related company, linear analysis executed on the FEA of the spring was more convenient were obtained.

Keyword: Turkish automotive customer usage, Leaf spring, Finite element, Fatigue analysis, Palmgren-Miner rule

---

[1] Corresponding autor.Tel.:+90 532 628 4660, E-mail adresses:senerarif@hotmail.com,arifsenolsener@aydin.edu.tr

(Arif Senol SENER)

1 Introduction

As the design development process are decreased from five years to two years over the last decade, automobile manufacturers are looking for advanced techniques to facilitate more rapid development such as service load data acquisition and analysis method [1,2]. Typical automotive design requirement are include the following: high stiffness, good fuel efficiency, smooth ride and handling, occupant comfort, drive characteristics. These requirements must be achieved along with adequate durability and reliability of the vehicle within the warranty timeframe [1]. Durability deals with the material fatigue. This kind of defect can be encountered on old or high millage vehicles. The durability of the vehicles depends on three important parameters: design geometry, material properties and loading environment. One of the parameters of loading environment is road roughness. Under normal conditions, vehicles are exposed to occasional high loads. It is important to have accurate statistical descriptions of these high loads, which are often caused by road irregularities [3]. Road quality can vary dramatically from country to country .As such automobile manufactures should set quality and durability design constraints in accordance with customer expectations in the target market. To take preventive action on durability defects, which can occur due to weak design and process, manufactures need accelerated fatigue tests and simulations methods. Durability tests are necessary to adapt vehicle performance to customer expectations [4].

Today, automobile manufactures use four durability test methods: fatigue analysis based on Finite Element Analysis (FEA), test rigs, test benches (one particular actuator test), and a accelerated test tracks.

The most popular method is used for the determine load spectrum for the whole life of vehicle is customer usage based methods. One example of a customer usage study which include dry and wet ground usage of tractor and agriculture and non agriculture tractor usage aim and also regional tractor usage examination is a study on a tractor usage in India, which was performed by **E.T.E.C.** (Eicher Tractors Engineering Centre) and **A.R.I.A.** (The automotive Research Association of India) [2]. Another example is a customer usage study performed by FIAT Co. for Brazilian and Italian markets. As we know that Brazil and Turkey haven't special proving ground in order to make test on standard fatigue road for the development of the new car models FIAT Co. compared proving ground profile effects of Italy and Brazil's public roads in addition customer usage effects on the vehicles by using frequency based fatigue life [8].

Differences of this study;

- Firstly, Turkish customer automobile usage profile was determined by questionnaire method. Holiday time and the distance lived from the home which is the one of the parameter of the questionnaire has been done by FIAT in 1993[9]. FIAT had accepted the holiday concept as the interval of holiday more than three days and if the distance is far away more than 300 km from the residence area. In our study the holiday concept is restudied and holiday interval was decreased from one week to three days and the holiday distance was accepted 300 km from the residence area were applied on the Turkish customer in 2001 as a questionnaire[10,28].

- Secondly, on the other studies road roughness fatigue characteristic effects on the vehicle were acquired both from the public roads (city roads, intercity, mountain and highway) and also mixed some special proving ground data. But in this study, the road roughness data were acquired only from public roads and instead of special proving ground effects very heavy village roads including mostly potholes and sharp curves and rocked bad road profiles were added due to the lack of standard proving ground in Turkey.

The road fatigue characteristics were measured totally from one city to another city since to make a comparison on different roads effect and to form new reliability roads that are necessary during the process and pre-series production around the interested factory. The design of test roads is extremely important for accurately simulating vehicle life. In the following section a methodology for defining test roads for a light commercial vehicle is explained.

2 Methods and Analysis

Durability tests for a vehicle or component must simulate the entire load spectrum (MP:mission profile, Turkish general road fatigue characteristic,) experienced during normal usage. This means that the tested load spectrum must cover all anticipated task and conditions during the lifespan of the vehicle [12]. Accordingly, automobile manufacturers must take into account anticipated customer usage within the target market before product production to ensure that reliability targets are met and customers are satisfied .Operational conditions, such as traffic, typical aim of the usage, loads on the vehicle, geographic and climatic conditions, numbers of vehicles per person, are dependent on the country and geographic location where the vehicle will be used. The service life of a vehicle component largely depends on the loading conditions during use [12,28]. For design and test

purposes, it is necessary to define a representative loading spectrum, which should be used for design evaluation as well as for derivation of a load spectrum for durability tests.

Load spectrum parameters includes usage, structural behavior and operational conditions are depends on each other and must be properly taken into during the procedure to determine a representative design spectrum. Vehicle utilization and driver behavior are critical factors in evaluating structural behavior, vehicle dynamic properties and design. Road quality and type are key factors in estimating operational conditions. If data about usage and operational conditions are known, it is necessary only to adopt the loads related into the vehicle when determining the load spectra of a new vehicle. Once this determination has been made, one must define the correlation based on vehicle usage and operational conditions **[12]**.

Today there are two methods that are used to determine customer usage; the questionnaire method and the black box method.**[13,9,14**]

2.1 General description of a questionnaire method

This method implements a large telephone survey designed to acquire information about the distribution of route types (city, extra urban, mountain, highway), the distribution of loads(driver without load, driver and half load, driver and full load, customer education level, and the purpose of vehicle usage**[12,2].**

In this method after acquiring the questionnaire results, a road test simulation with an equipped vehicle / vehicles is performed to collect data on public roads, during various maneuvers (braking curving, accelerating) during power generation (engine and transmission components), in various locations, on various types of roads (city, intercity, mountainous, rural) and by multiple drivers **[11]**.

Measured data are processed for spikes and are filtered. Frequency analysis and arithmetic manipulations are performed to generate inputs for fatigue analysis **[8].** Since the road excitation signals are formed from periodic and random data, it is necessary to process the data with range pair, rain flow, level crossing counting methods to compare the signals in a statically meaningful way **[15, 8].** Statistically counted road excitation signals are transformed into normalized unit values. Then the signals are divided according to road type and load condition. By means of extrapolation, the factory's prediction of the useful life of the vehicles is determined. Many companies specify the design requirements to match the 90 th percentile or 95 th percentile of anticipated customer usage (based on mileage). In Figure 3 , the target mission profile (which is consisted of roads excitation signals taking into account 90 th percentile distribution of customer automotive usage and load and the target of MP for the light commercial vehicle is 200.000 km) are obtained for each sensor. The methodology is based on the following principle; *if same inputs are reproduced, then the same damage will result.* **[8,11].**

After forming MP, it is then possible to find mixes of tracks or rig drivers that match the inputs for accelerated test tracks that is corresponding same damage effect of MP. If the same inputs are maintained, matrix calculation of various forms will provide a scheme for assessing the mixture of road excitation signals, and for optimizing the test length or test time.

$$A[X1]+B[X2]+C[X3]+\ldots\ldots+Z[\ Xn] = [Y]$$

Where A, B, C,……..Z= Multipliers of test data

[X1],[X2]…..[Xn] = Matrix of test measurements

[Y] = Matrix of customer target measurements

This can be interpreted quite easily as: A times track X1, followed by times track X2 ,and so on, so that it gives the same effect as Y of the target **[11]**

3 Application examples

In this study for road test acquisitions one FIAT Doblo Passenger car LCV (light commercial vehicle) was chosen and it is designed for transportation of goods and passengers. The algorithm of the study is explained in Figure 1.
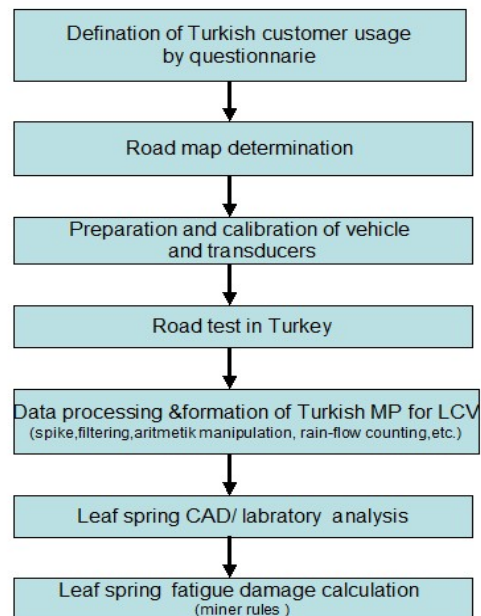

Figure 1 Algorithm of the study (**10**)

3.1 Determination of the Turkish mission profile

3.1.1 Questionnaire application

Because the questionnaire method allows for faster data collection, provides flexibility on data elaboration and reduces cost compared to the black box method. As such, it was the method of choice in this study. The Turkish customer usage profile of an LCV that is used for both transporting goods and passengers was developed based on a questionnaire administered to Turkish customers with the assistance of me and also automotive dealers representing the LCV manufacturer.

3.1.2. Definition of road map

The test road map which was necessary for data acquisition on the roads, represented 90 % of customer usage in Turkey. Roads were divided in four groups: City road usage was found to be most common around the Istanbul district. Mountain roads were most common in the Black Sea region. Intercity roads which include hot climatic and curved road conditions were found around the Mediterranean Sea. Road in Central Anatolia were characterized by high altitudes, hot temperatures, and long distances between cities. For the highway roads characteristics Istanbul-Ankara and Adana- Gaziantep roads were subjected to data acquisitions. Those test roads are shown in Figure 2, which shows sale percentages of LCV's according to region, region where customer claims tended to occur, previous model experiences, climatic conditions, and geography.

Figure 2 MP road test map **(10)**

3.1.3 Data acquisition to define the Mission Profile target

For data acquisition and fatigue simulation, a vehicle was equipped with load transducers; two strain-gauges on the leaf spring, one strain-gauge on the transmission shaft and one strain-gauge on the steering road. The vertical loads created by road roughness, maneuvers and acceleration were measured by 2 half- bridge strain-gauges on the principal stress axis on the leaf spring. which were prepared, calibrated and analyzed in the laboratory before being assembled on the car.

In this study, the measurements were carried out with a vehicle equipped with sensors and driven over customers chosen roads by a test driver and an engineer at full loads.

3.2 Evaluation of road data

The data analysis method used in this study is shown in Figure 3. For fatigue data collection, we could not

measure external loads directly. Rather we measured their reactions at certain points of vehicle parts [12]. The collected signals were processed by spike analysis, filtering, arithmetic manipulation, frequency analysis and statistical counting operations [16].
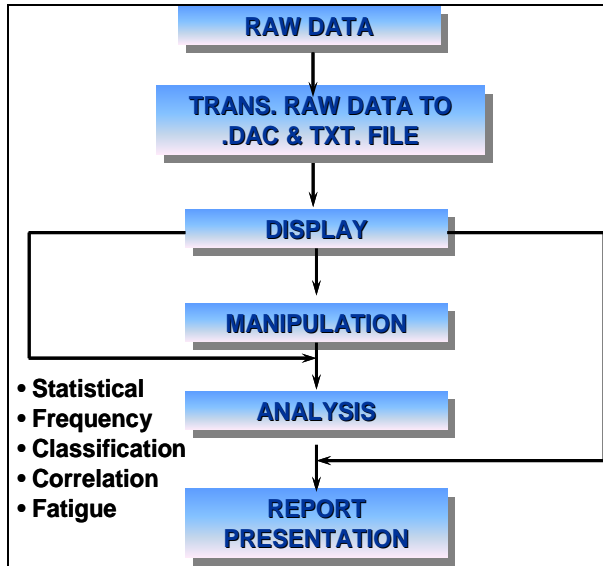

Figure 3 Algorithm of data processing (17)

3.2.1 Spike analysis

During data acquisition some ''spikes'' occurred due to environmental and physical factors (such as voltage drop, magnetic field effects, etc). These spikes were eliliminated by visual and statistical methods [16].

3.2.2 Filtering

In Figure 4, low amplitude signals with frequencies above 100 Hz are not significant for fatigue analyses and therefore were removed from the original data by means of a low-pass filter [16].
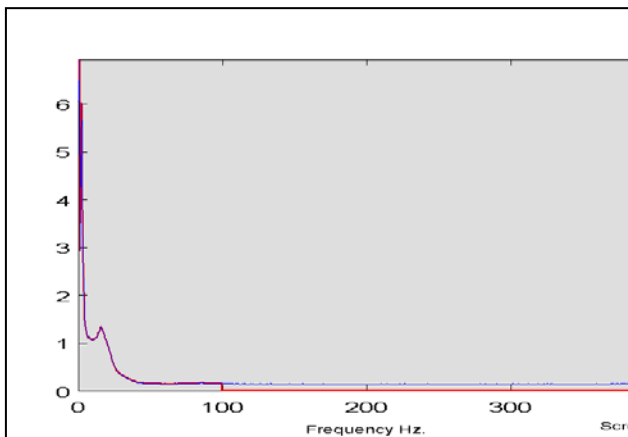
For vehicle suspension parts, the frequency range of interest for fatigue analyses is between 40 and 60 Hz. For road simulations, it is generally accepted that excitations over 100 Hz can be neglected [18].

3.2.3 Arithmetic manipulations

An arithmetic manipulation is used for summation and extraction and multiplication of the signals. Each test data are acquired which is not useful for the fatigue life calculation, before vehicle movement is extracted.

3.2.4 Statistical road excitation signal counting

The road signal is formed from random and stationary signals that are time- varying. In addition, signals from roads with heavy surface damage are formed from deterministic (non periodic) potholes, railway crosses, etc. with create impulse and shocks effects on the vehicle. Time –varying signals should be converted to an equivalent value, independent of time, for comparison. The statistical counting method was applied to achieve this conversion [15, 19].

The leaf spring strain-gauge data was reduced to foreseen 200.000 km MP values using the rain-flow statistical counting method takes into account the mean amplitude of the force beside the time variable force exposed on the particular.(The time –varying leaf spring strain's rain-flow histogram is shown in Figure5.

The rain flow method was used for statistical analysis of the strain-gauge data because it is more sensitive than other methods [15, 20].
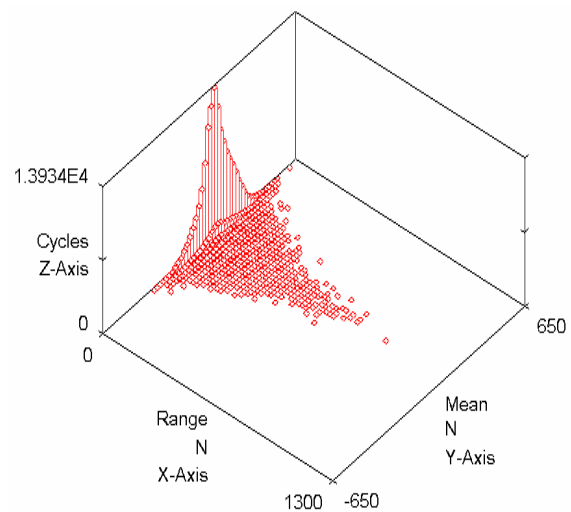

Figure 4 Data filtering (10)

Figure 5 Rain flow histogram (10)

3.2.5 Forming mission profile target

Because each acquired data had different lengths, each measure was normalized to a constant, convenient distance in kilometers (i.e.; 1km or 10 km). Each normalized measure was classified according to road type (city, intercity, mountain, and highway).each road type was averaged within its class. Then each classified measure was extrapolated to the estimated target km of MP and then multiplied by the percent usage distribution the given road type based on the usage questionnaire.

3.2.6 Simulation of mission profile

The accelerated test track for the fatigue simulation was constructed from heavily damaged surfaces to decrease the test time. Although force, displacement, and acceleration are very important parameters for fatigue testing, the gear change rate, brake pressure, brake application quantity and engine torque parameters should also be taken into account. For this reason, one short accelerated test track that included all kinds of surfaces and characteristics was defined. This road was extrapolated to 30.000 km for fatigue simulations that corresponded to 200.000 km under normal usage.

3.3 Simulation of experimental data by finite element analysis

3.3.1 Modeling

The geometrical model of the leaf spring was created by measuring approximately 1000 coordinate points on the leaf spring with 3D measuring devices and a sensitivity of 0.0003 mm.

The CAD model of the leaf spring was created in Pro Engineer using the measured coordinate points. Then a 3D CAD model was exported to MSC Patran software to perform FEA analyses [21, 22].

3.3.2 FE modeling

Because the geometric model of the leaf spring does not contain complex structures, the isomesh method was used. The FE model of the leaf spring contained 5728 hexa-type elements and 9156 nodes.

During FE modeling of the leaf spring the critical points, sections and parts were meshed with high sensitivity along the primary aspect of leaf spring.

3.3.3 Load and boundary conditions

To verify the computer analysis results, the components were physically tested in the laboratory. Figure 6 shows the calibration of the strain-gauge that was mounted on the leaf spring using a certificated laboratory test bench.
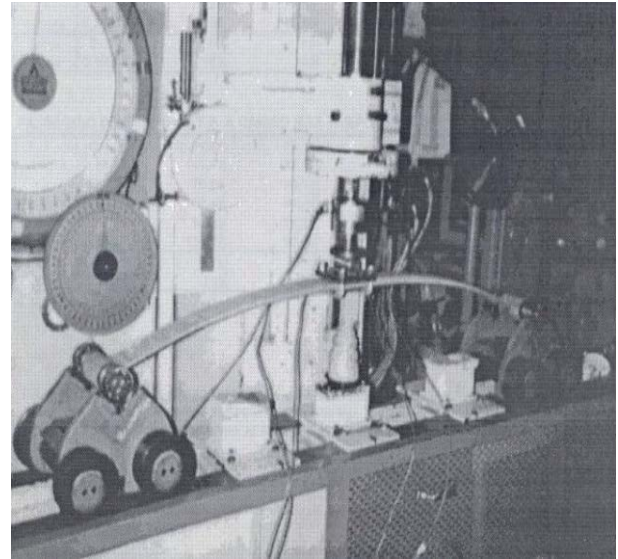

Figure 6 Test bench for calibration of the leaf spring **(10)**

To test the leaf spring each side of the leaf spring's bushing was fixed to the sliding carriages so that they could move with respect to the test bench without friction. At the same time, the center of the leaf spring was activated by a vertically fixed piston to simulate the kinematics of the component .As it can be seen in Figure 7 the leaf spring FE model was tested with two types of boundary conditions [23].

- **First boundary conditions of the FE model:**

The big bushing side of the leaf spring was fixed in the x-z plane and was allowed to rotate about its y axis, the small bushing of the leaf spring was free(i.e. it could rotate about the y-axis and displace along the x-z plane .

- **Second boundary condition of the FE model:**

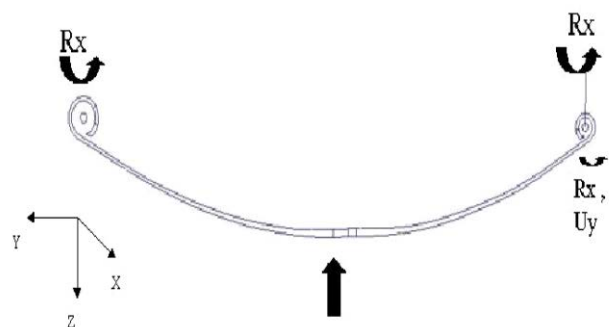The hub of the leaf spring was fully fixed, and each side of the leaf spring was free.

Figure 7 Boundary Conditions **(10)**

Table 1 shows the applied forces on the leaf spring and the measured strain data from the one strain gauge during the leaf spring physical calibration test in the laboratory.

The results of applying the physical loads from Table 1 to the FE model are shown in Table 2. When 100 daN is applied, 1293 με with the physical test, 1190 με with the computer analysis test are measured.

Table 1 Physical calibration test results for the first strain-gauge **(10)**

Physical Loading Force (daN)	Measuring Strain Value (με)
0	0
100	1293.2
250	3458.4
350	4952.8
500	7060

Table 2 FE static results of the leaf spring at first strain-gauge location **(10)**

FE RESULT OF THE LEAF SPRING CALIBRATION TEST				
Loading Conditions				
Force daN	Big bushing is fixed, small part is free only horizontal side		Hub is fixed, bushing are free only horizontal side	
	Linear Static με	Nonlinear Static με	Linear Static με	Nonlinear Static με
100	1190	670	1190	670
250	2970	1880	2970	1880
350	4160	2580	4160	2580
500	5940	3640	5940	3640

3.3.4 FE modeling of the vehicle's leaf spring

Figure 7 shows FE modeling of the vehicle's leaf spring. The main difference between the leaf spring mechanism on the vehicle and the virtual calibration on the computer is the lever arm that is fixed to the smaller side of leaf spring and to chassis of the vehicle. With these boundary conditions, when a vertical force was applied at the hub of the leaf spring, the right side of the leaf spring began to displace and the length of the leaf spring began to increase. As a result of these boundary constraints, the maximum stress in the leaf spring decreased by 2.7 %
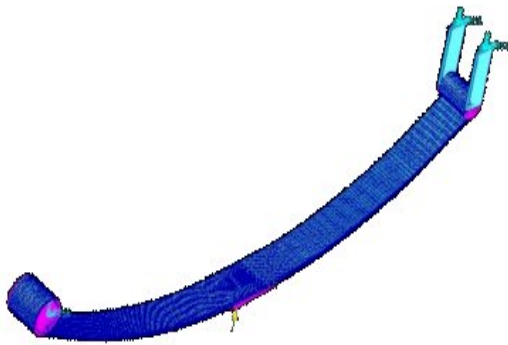
3.4 Static and fatigue analyses

3.4.1 Static and fatigue calculations

The geometry of components, materials characteristics and loading parameters necessary to complete the fatigue analysis based on finite element theory. These parameters are linear analysis results, dynamic load data and the material specifications [24, 25].

The linear static analysis of the leaf spring was executed using the most critical load (the most heavy damaged road surface effects) that was acquired during road tests in Turkey [10]. For the linear static analysis, the vehicle weight was summed as a pre-stress on the maximum road stress measured during the road tests. Figure 8 shows the maximum stress, which occurred in close proximity to the small bushing and was approximately 804 MPa according to the Von Misses method using the most critical load condition in the linear static analysis [24, 13, 17].
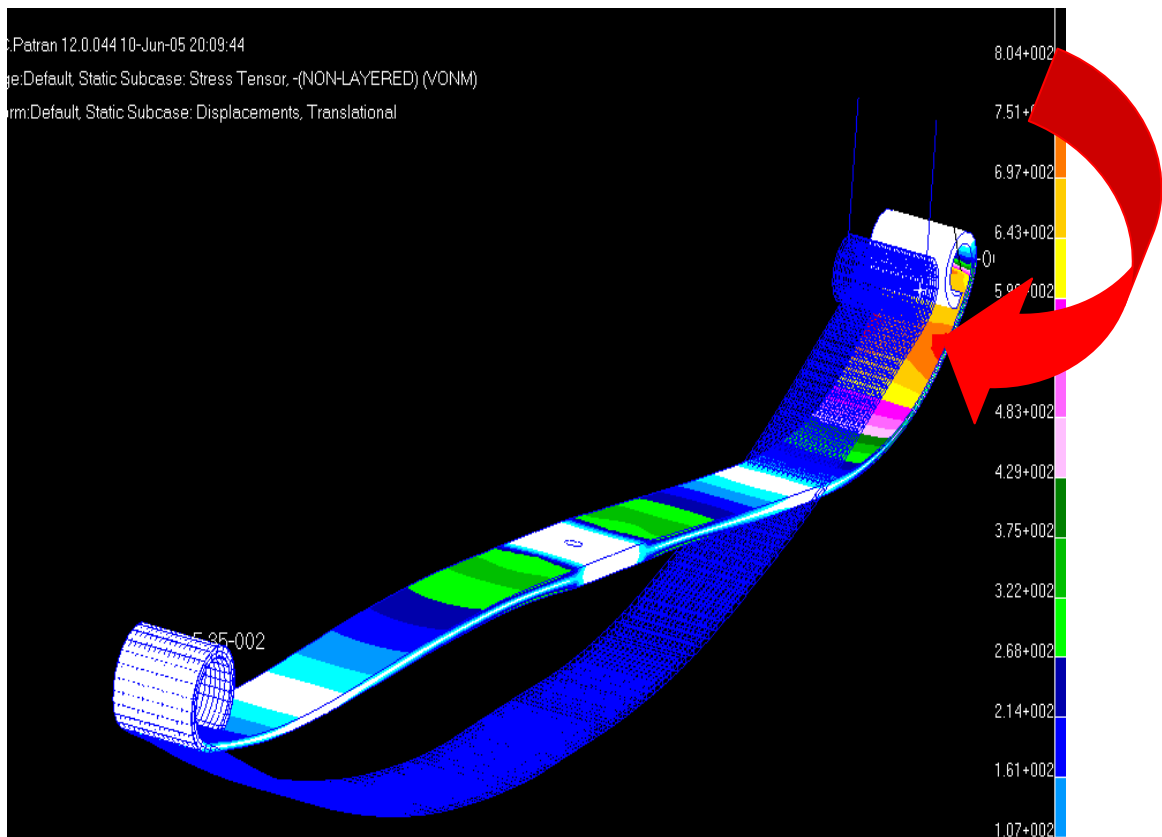

Figure 7

Figure 8 Linear static analysis results **(10)**

Figure 9 shows the Wohler line S (stress) - N (number of cycle) of the leaf spring's material characteristics. The maximum stress is much lower than the actual yield stress of the leaf spring material. In fact, it is half of the yield stress.

The S-N Method was preferred because the value obtained from the data from different kind of roads in Turkey is much lower than the material yield stress [24, 26].

For the statistical analysis of the leaf spring, the maximum load data, measured during the road tests, and the rear left axel vehicle weights were superimposed using the FE model. A 4540 N load was obtained. The rain-flow histograms of stress distribution of the MP and accelerated test tracks are shown in Figure 10 and 11, respectively [10].
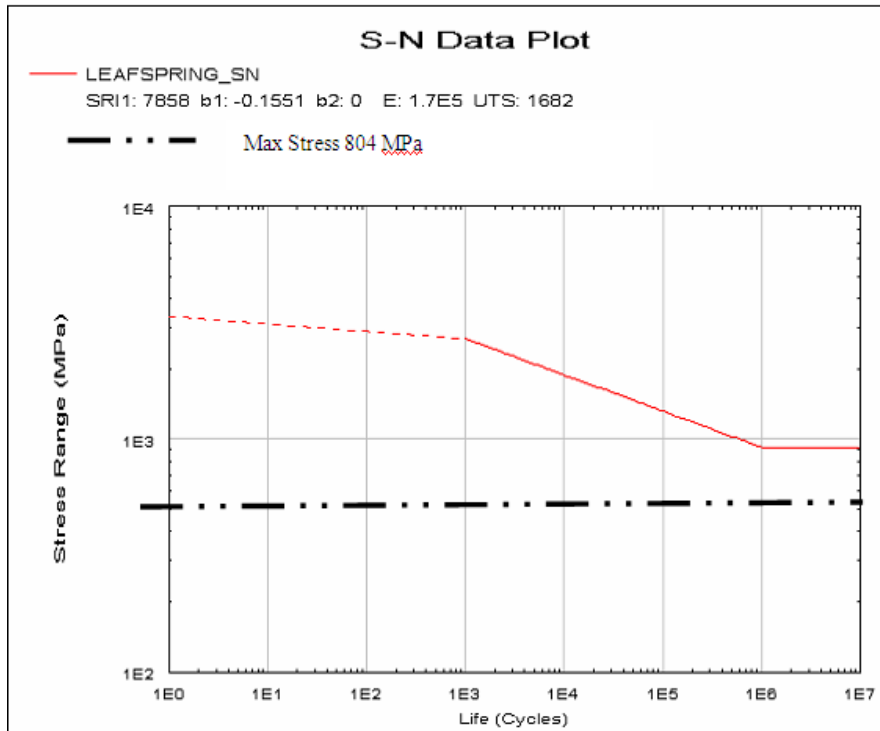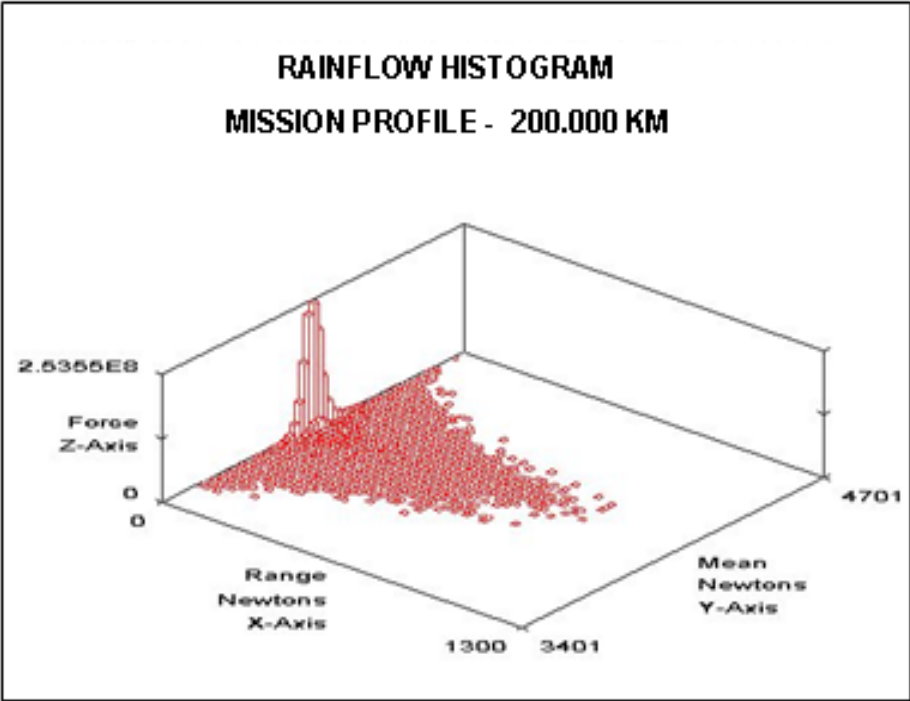
Figure 9 Material S-N data (**10**)

Figure 10 MP (200.000 km) histogram **(10)**

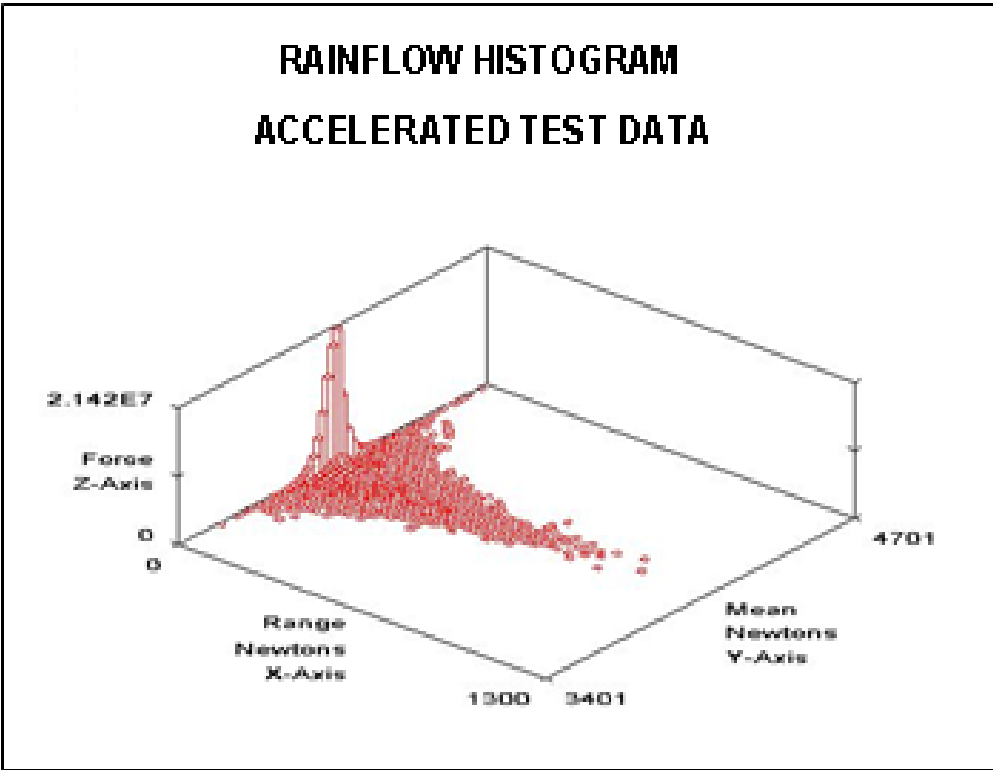**Figure 11** Accelerated test data (30.000 km) histogram

In Figure 12 the unit rain-flow histogram that is calculated by superposing the vehicle static weight and the most critical dynamic load spectrum is shown.
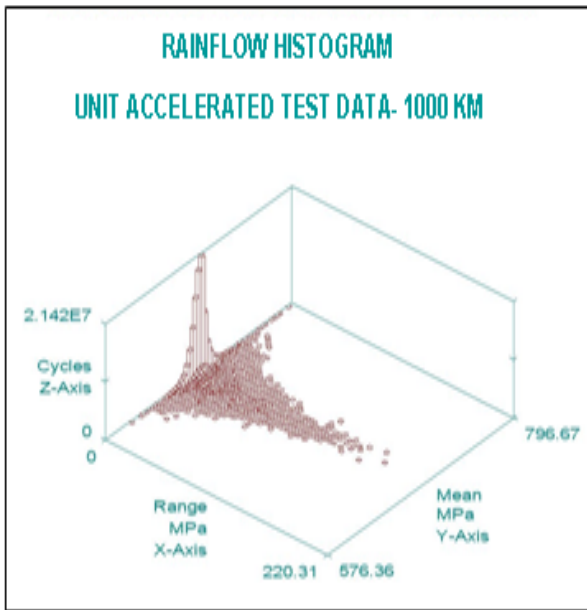

Figure 12 Unit accelerated test histogram 1000 km **(10)**

Table 3. Aim of usage LCV in Turkey **(10)**

Aim of usage	
Usage	%
Home-work-home	29
Work-to-work	55.3
Shopping and leisure	4.7
Weekend	5.4
Holiday	5.5

In **Figure 13** the load spectrum of the Turkish MP (200.000 km) matched with color yellow and the accelerated test track 30000 km matched with color pink and reliability roads 30000 km matched with color bold blue are shown. These load spectra have been verified in terms of a fatigue damage analysis according to the Palmgren-Miner damage rule. The damage ratio between the accelerated test track 30.000 and the MP 200.000 km was 0,7.

4. Results

The automotive customer usage of light commercial vehicle was divided into four main categories city, intercity, highway and mountain. The cargo versions of these vehicles had the following mission profile. 25% city, 35% intercity,30% highway, and 10% mountain. Whereas for the passengers versions of these vehicles the mission profile was 50 % city, 24% intercity, 20 % highway and 6% mountain were derived from questionnaire. Compared one of the European countries, the major difference is found in the amount of city usage, which is 50%in Turkey **[18, 10]**. This means that these vehicles are mostly used in Turkey for city transport but mostly used in one of the European country for mountain, intercity and highway transport. The result of aim of usage of LCV in Turkey is presented in Table 3. The primary purpose of the LCV is for work –work-travel.
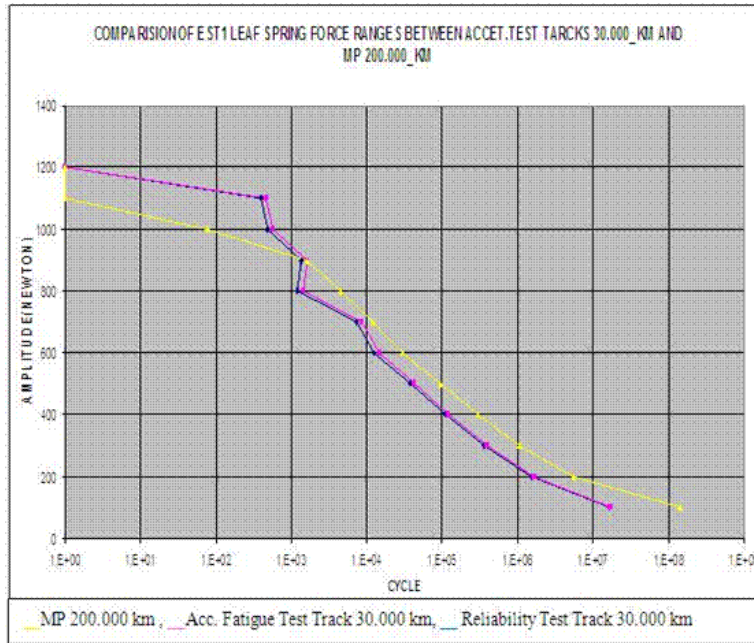
Figure 13 Comparison of leaf spring force data between mission profile and accelerated track

5. CONCLUSION

In this analysis , a Turkish customer usage profile was developed based on a questionnaire administered to Turkish light commercial vehicle users.

A comparison of LCV usage between one European country and Turkey was presented. This revealed that the Turkish customers use this type of vehicle for city driving twice as much as typical users in one of the European country.

The primary purpose of light commercial vehicle usage in Turkey is work-to-work and work-to-home-travel. A mission profile of LCV usage specific to Turkish drivers has been developed. After processing, classifying and normalizing different signals, a mathematical mission profile (200.000 km for a typical Turkish customer) has been calculated.

Accelerated reliability and fatigue road tests were performed by applying the index and computer –aided fatigue method to data measured from several vehicle-mounted sensors **[18].**

The linear analysis method that is used in virtual analysis of the structure gave more precise results on this kind of leaf spring instead of non-linear analysis. No significant differences between two tested boundary conditions were found (i.e. bigger bushing that turns

freely or while the smaller bushing that is free in the x axis).

It has been observed that computer-aided analysis can be used as an alternative for laboratory tests because the results that were obtained from both methods were quite similar.

Based on the these results , using computer aided calculation methodologies is both cost effective and can help develop better, market specific products.

The results of this study could also be used when developing new automobile models, before construction of real prototypes and pre-serial production cars.

6. Acknowledgements

7. REFERENCE

[1] Heyes,P., Lin, X.,Buczynski,A., Brown,M. (1997)'Application of Biaxial Plasticity and Damage Modeling to the Life Prediction and Testing of Automotive Components *"5 th International Conference on Biaxial /Multiracial Fatigue and Fracture Cracow*, Poland , Ncode International Limited.

[2] Paul,P.K.,Dunga,R.K. and Verma,A., Minakar ,A.V. and Raju,S.(2001),'Techniques for Accelerated Design Validation of Tractor Chassis', *SAE Paper 2001-01-0050.*

[3] Bogsjö,K(2006)'Development of analysis tools and stochastic models of road profiles regarding their influence on heavy vehicle fatigue', *Vehicle system Dynamics* ,44:1,780-790.

[4]Kouta,R.,Play,D.,(1999)'Correlation procedures for fatigue life determination', Journal of Mechanical Design,vol.121/289.

[5] Ahlin.K., GanlundJ.and Lindström,F.,(2004)'Comparing roads profiles with vehicle perceived roughness', *Int. J. Vehcile Design* ,Vol.36,Nos.2/3,pp.270-286.

[6] Huizinga,F.T.M.J.M.,Van Ostaijen,R.A.A.and Slingeland,A.Van Osten (2002)'A practical approach to virtual testing in automotive engineering', *Journal of Engineering Design* , 13:1,33-47.

[7] Medepalli,S.and Rao,R.,(2000)'Prediction of road loads for fatigue design –a sensitivity study', *Int,J.of Vehicle Design*,Vol.23,Nos.1/2,pp,161-175.

[8] D'aprile Filippo, Macni Marco, Bruder Thomas, Riefaoghe Christophe (2001),'' Structural Characterisation of Vehicle on a Rig Test Versus Different Road Profiles Analysis of Experimental Results, *ATA* vol.54 .n 7/8 Luglio –Agosto (LMS International, Belgium,-Memoria presentata al convegno florance Ata , Frienze).

[9] Fantacchiotti.,M., Vianello.M.,(1994) ' Gradual Improvement of the vehicle reliability up to the target value' FIAT Auto S.p.A. Design Engineering Department, *4th International Conference ,Italy, Florence ATA New Design Frontiers for more efficient ,Reliable and Ecological Vehicles March 16-17-18*

[10] Şener,Ş.A., (2003),' Hafif Bir Ticari Otonun Arka Süspansiyon Yaprak Yayının Türkiye Koşullarına Göre Yorulma Analizi ' PhD thesis. Yıldız Technical University, Istanbul, Turkey.

[11] Maineri.G., Ensor D.F., (1999) '' Case study-Complete customer usage profiling example raw data through track correlation to accelerated rig drive in ''4'' days. AfIiliation : Iveco (Italy) - nCode (UK)

[12] Grubisic,V. (1994) '' Determination of Load Spectra for Design and Testing '' *Int.J.of Vehicle Design* , Vol.15 nes.1/2 ,pp 8-26.

[13] Fantacchiotti,M., Vianello. M., (1992) ''Accelerated reliability test for vehicles and correlation with actual use ''*Proceeding of the 3rd International*

conference A.T.A. Innovation and Reliability in automotive design and testing '' (Palazzo degli affari e palazzo dei congressi) Frienze ,Italy, April 8-9-10,

[14] Marchesani.C.,Parmigiani.F.,Vianello.M.,(1979) 'Integrated method to define the mission profile of a passenger car 'FIAT Auto S.p.A., Study Report (in Italian)

[15] ASTM Standard E 1049-85 '' Standard Practices for Cycle Counting in Fatigue Analysis'',(Reapproved 1997) Philadelphia.

[16] MSC nSoft v5.2 User Manuel (1999).

[17] MSC Online Help Documentation (1999) Institute of Technology.

[18] Pisarri.N.,(1998) Ricerca del profile di Missione vetture segment B Turchia, '' Turkish Ciklo 'Relazione prot.N°. 1-1998, Arese,04-Febraio.D.T.S.V. Affidabilita' e Terreni Prova Laboratorio Misure '', Study Report (in Italian)

[19] Bishop.N.W.M., Kerr,S., Caserio,A.,(1999)'The Fatigue Damage Caused to Vibrating Automotive Components '',*1 st MSC World- wide Automotive User Conference*, September 20-22.

[20] Bishop, N.W.M., Lack,L.W., Li,T., Kerr,S.C. (1995) ''Analytical Fatigue Life Assessment of Vibration Induced Fatigue Damage ''MSC World Users Conference, Universal City, A.

[21] MSC Patran(2001).

[22] Pro-Engineer (2001)

[23] MSC Nastran Getting Starting User Guide (2001).

[24] Bishop, N.W.M., Sherratt,F,(2000) 'Finite Element Based Fatigue Calculations 'NAFEMS LTD (International Association for the Engineering Analysis Community) www.nafems.org.

[25] MSC /FATIGUE V8 User Manuel, MSC Corporation, Los Angeles, A, (1998).

[26] The Ncode book of Fatigue Theory (2000) Ncode Technical Reference Book V:4.3. Document rel 1.0.

[27] Miner.M.A.,(1945)'Cumulative Damage in Fatigue', *Journal of Applied mechanis*,ASME,vol:12,pp.159-164.

[28] Şener,Ş.A., (2011),' Vehicle component fatigue life definition based on the finite element method according to a customer usage profile '' *International Journal of Automotive Technology* (in review)