Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 14
ISSUE 1-2
January-February
2006

Estimation of fatigue damage caused by actual roads and maneuvers on proving ground

G.H. Farrahi [a,*], A. Khalaj [b]
[a] School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran
[b] Automotive Industries Research and Innovation Center of Saipa, Iran
* Corresponding author: E-mail address: farrahi@sharif.edu

Received 15.11.2005; accepted in revised form 31.12.2005

Analysis and modelling

ABSTRACT

Purpose: The objective of this paper is to estimate the cumulative fatigue damage in a vehicle component and to calculate the number of cycles driven on the proving ground to achieve the equivalent accumulated fatigue damage in design life.
Design/methodology/approach: In order to achieve our objective, using ADAMS software, standard roads and proving ground events on which the vehicle model was to be driven were simulated. The load time history results were applied to an FEM model created in MSC/Nastran. Modal transient dynamic analysis was used to obtain the stress time history in the test component.
Findings: The results showed that fast cornering has a greater damage effect than slow and moderate cornering. For primary evaluation of fatigue life (in our case) the cornering analysis is sufficient. The proving ground events had much more destruction effect than actual roads as the fatigue damage accumulated on our test component. Driving 1568 cycles (2462 km) on a proving ground was equal to driving 200000 km on actual roads.
Research limitations/implications: The next stage in this research may be to study the effect of dimensions of proving ground events on accumulated fatigue damage.
Practical implications: By using CAE and VPG the time and cost of developing the new models of vehicles decreases.
Originality/value: The number of cycles which should be driven on the studied proving ground to achieve the accumulated fatigue damage in design life has been esimated.
Keywords: Numerical technique; Fatigue; Proving ground; FEM; ADAMS

1. Introduction

The roads on which a vehicle is driven during its design life, have different effects on the fatigue damage it suffers. This also depends on the speed and the type of driving (straight, cornering and braking) to which the vehicle is subjected during its design life. A reasonable estimation of accumulated fatigue damage during a vehicle's design life is achieved by combining the various maneuvers likely to be experienced in the design life of the vehicle with real weight factors.

It is obvious that durability tests are very time consuming so proving grounds have been developed for reducing the time of vehicle durability tests. The most important feature in the proving grounds is the amount of damage accumulated in vehicle parts as the result of each cycle in a proving ground. Initially, only actual tests were used for the estimation of this fatigue damage [1]. In recent years by developing and extending Computer Aided Design (CAD) and Computer Aided Engineering (CAE) software, these analyses are carried out entirely virtually [2,3,4]. This process is called Virtual Proving Ground (VPG). By using VPG the time and cost of developing new vehicle models decrease. This reduction is achieved because a virtual, instead of an actual, prototype is made at the design stages, and the modifications are applied to the virtual model until the desired model has been achieved. Finally the actual prototype can be manufactured with minimum faults. Nowadays, the target is Zero Prototyping. Using dynamic analysis software alongside an FEM software is the most common way to do the VPG analysis.

In this paper, the fatigue damage caused by driving straight on roads with different qualities and driving in cornering and braking states has been estimated in a sample vehicle component (rear spindle), using ADAMS and MSC/Nastran packages. By combining the straight, cornering and braking maneuvers a reasonable prediction of fatigue damage accumulated during a design life has been calculated. Also, by driving the virtual model on proving ground events the damage produced in the spepcified part has been calculated and by taking into account their shares at each cycle of the proving ground the fatigue damage per cycle has been estimated. Finally the number of cycles which should be driven on the proving ground to reach the equivalent accumulated fatigue damage in design life has been calculated.

2. Actual roads and proving grounds

Road surface quality varies in different regions. So the ISO categorized roads into 8 levels [5]. The surface irregularity of roads is represented in PSD (power spectral density) form. By taking the inverse, the road profile (road height versus road length) can be achieved (Fig. 1). Road type A is a very good and smooth and type D is a poor and rough road. The road quality in every region can be expressed as a combination of these standard roads.

The proving grounds have several events to accelerate the durability test of the vehicle. These events and their shares in each cycle are designed by simulations and tests. Some of the events have been shown in Fig. 2 [3].

The standard roads and proving ground events, on which the vehicle model is driven, have been simulated in Adams software (Fig. 3).

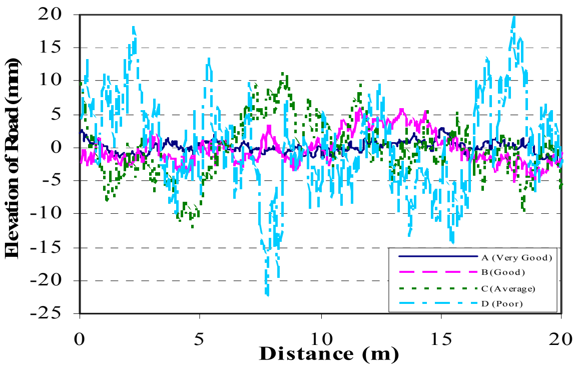


Fig. 1. Sample road profile of ISO standard roads [5]

3. Details of the komponent

The vehicle part used for this study was the rear spindle of a passenger car. The spindle is manufactured from a steel JIS-S45C with a tensile strength of 686 MPa. Fig. 4 shows the location and the dimensions of the spindle.

4. Loads and stress time history

For straight driving on the various roads (with different qualities) the driving speeds have been chosen according to the road quality (Type B, V=100km/h; Type C, V=75km/h; Type D, V=50km/h; Type E, V=25km/h). For examination of the cornering effect, three conditions have been considered:

1-Slow (30km/h on road C, Radius=30m)

2-Moderate (40km/h on road C, Radius=30m)

3-Fast (50 km/h on road C, Radius=30m).

For braking, a harsh state of 50km/h has been considered. For proving ground events according to test standard the driving speed was 40km/h.

In Figs 6 to 9 the sample outputs of this stage have been shown. F_x is the force in the X direction and along the length of vehicle and F_z is in the Z direction and vertical.

It is evident that loads caused by proving ground events are much higher than those in straight driving on actual roads. In Fig. 8 it can be seen that the loads in fast cornering have been increased considerably compared with straight driving. These curves show that straight driving on road type C has produced fluctuations while the cornering effect on the flat road has produced a higher mean value. Fig. 8 also shows that braking loads did not have any tangible effect comparing to straight driving.

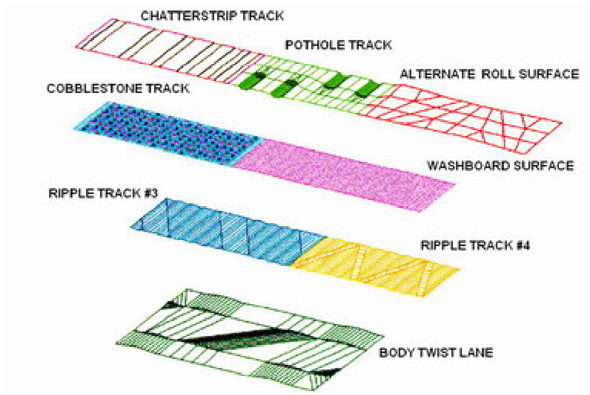


Fig. 2. Some events in proving grounds

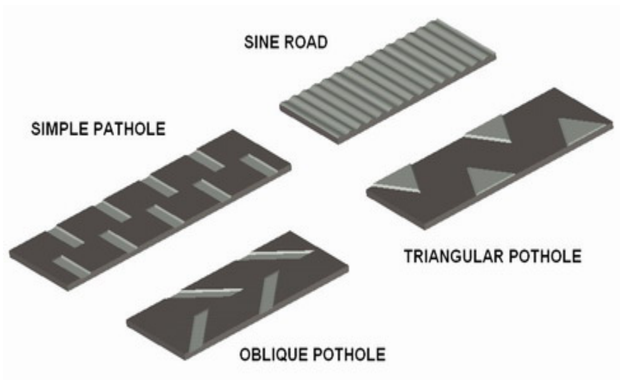
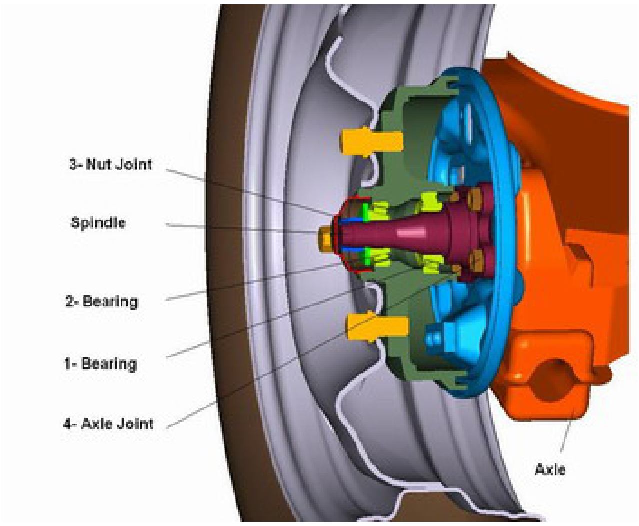


Fig. 3. Events in actual proving ground



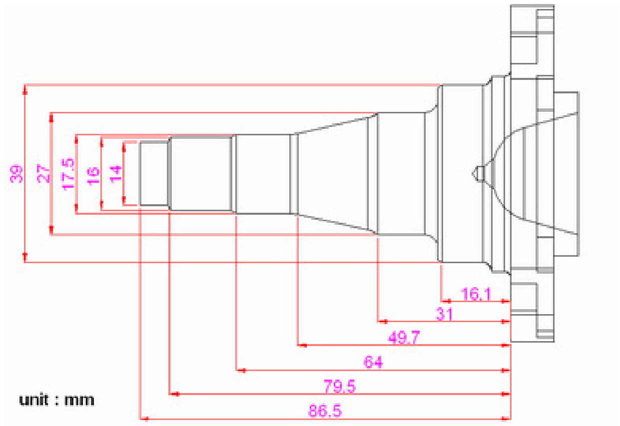


Fig. 4. Details and dimensions of spindle

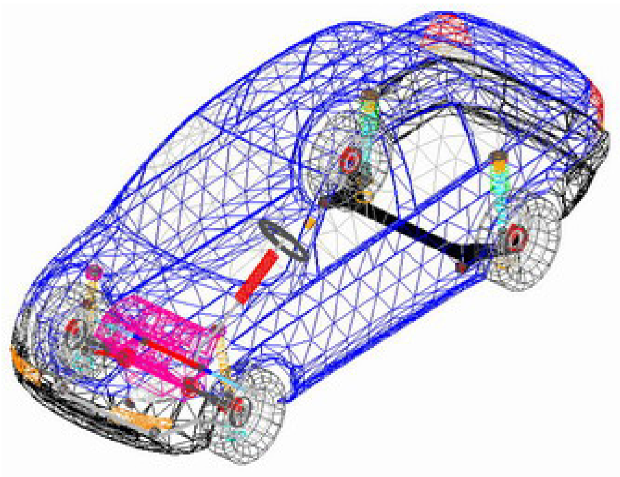


Fig. 5. Full vehicle model in ADAMS

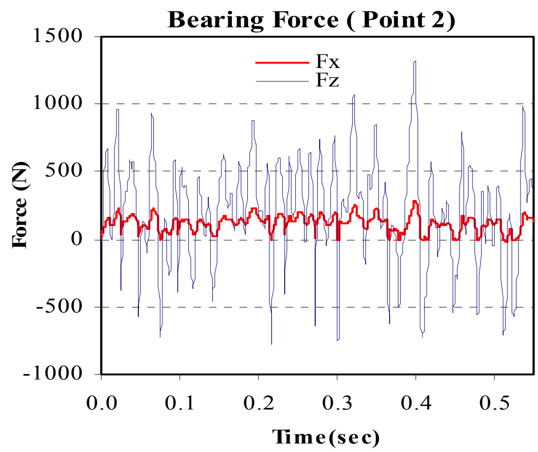


Fig. 6. Time history of loads in straight driving on road type C

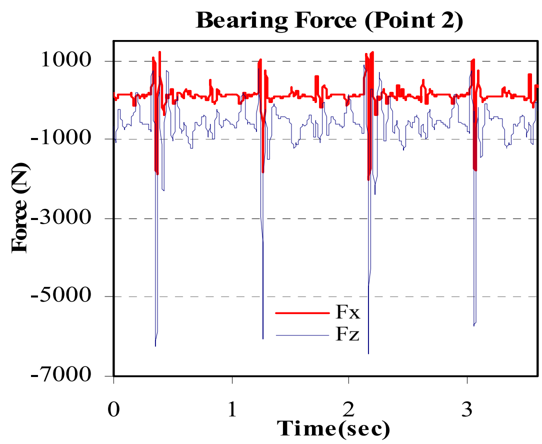


Fig.7. Time history of loads in driving on simple pothole

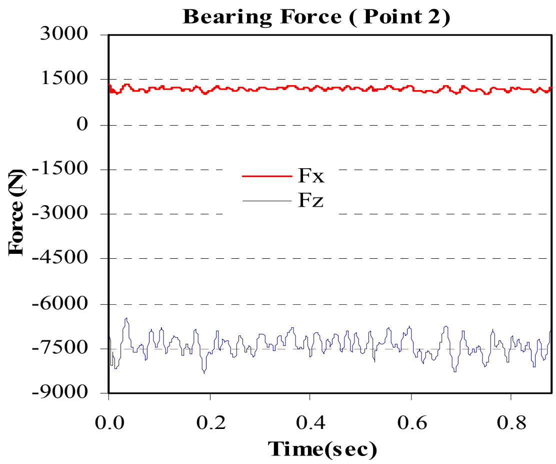


Fig. 8. Time history of loads in fast cornering

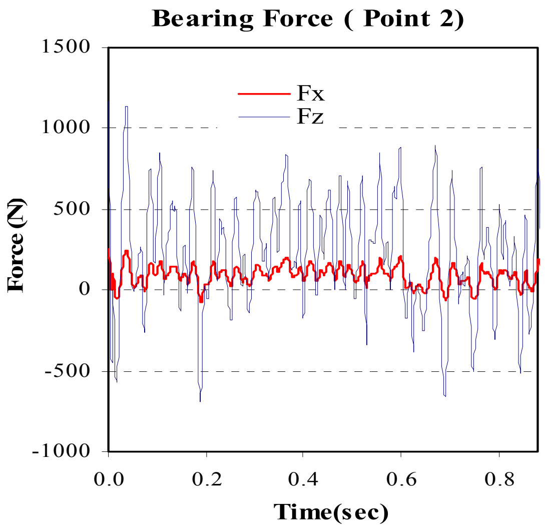


Fig. 9. Time history of loads in braking

5. Finite element model grounds

Fig 10 shows the FEM model created in MSC/Nastran. The load time history results have been applied to the FEM model. Modal transient dynamic analysis has been employed to obtain the stress time history in the test component [6].

Figs 11 to 13 show some results of this analysis in a critical element. In Fig. 11 it can be seen that the Von-Mises stress resulting from driving on a proving ground event (triangular event) is much higher than those driving straight on the road type C. Therefore, the destruction effect of the proving ground events is higher than that of driving on the actual roads. Fig. 12 shows the effect of fast cornering. The vehicle has first been driven straight then put into a circular path and returned to straight again. The cornering effect increases the mean value of the curve. Fig. 13 also shows that the braking is not influential in comparison with normal straight driving.

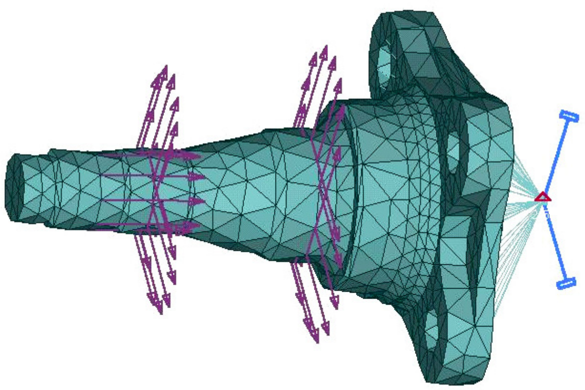


Fig. 10. Spindle and its FEM model

6. Fatigue damage in design life and proving ground grounds

By using the stress time history, a computer program to calculate the fatigue damage and to predict the design life has been prepared. The Rainflow Method for cycle counting, Goodman theory and Palmgren-Miner theory for calculating accumulated damage have been used in this program [7-10].

The stress-life equation for the spindle is the following:

$$\frac{\Delta\sigma}{2} = \sigma_f'(2N_f)^b$$

where

σ_f' (fatigue strength coefficient) = 1031

b (fatigue strength exponent) = -0.12

The results of this program have been shown in Fig. 14. In this Figure the fatigue damage per kilometer for driving on standard roads has been presented. The damage in fast cornering and straight driving on roads type E and D is much more than those of the other cases. The experiments have shown that the main source of fatigue damage is driving on 5-10 percent of roads which are similar to cornering and straight driving on road types E and D.

As the quality of roads in different regions varies, the roads in a region can be expressed as a combination of standard roads and maneuvers (straight, cornering and braking) taking into account their weight factor [11].

$$R_e \equiv (\alpha_{Straight} + \alpha_{Braking} + \alpha_{Cornering})X$$

R_e = Equivalent road

X = Design life distance

$$\alpha_{Straight} + \alpha_{Braking} = 95\%$$

$$\alpha_{Cornering} = 5\%$$

Because the damage effect of braking in this study is negligible, its occurrence percent has been included into the straight driving.

For straight driving according to the regional roads quality, the three types have been considered with the following weight factors:

$$\alpha_B = 65\% \ , \ \alpha_C = 20\% \ , \ \alpha_D = 10\%$$

The weight factor for cornering can also be detailed as:

$$\alpha_{Slow} = 2.5\%, \ \alpha_{Moderate} = 1.5\%, \ \alpha_{Fast} = 1\%$$

Now the effect of each maneuver in 200000 km can be calculated. Results have been shown in Fig. 15. Fast cornering has the most effect on fatigue damage. In straight driving the road type D has more effect than the others. The accumulated fatigue damage for 200000 km driving on equivalent roads has been shown in Table 1.

Table 1 shows the fatigue damage per kilometer for driving on proving ground events. The cyclic fatigue damage of proving grounds can de calculated. One cycle of a proving ground consist of:

1 Cycle = 54 Simple potholes + 54 Oblique potholes + 16 Triangular potholes + 770 Sine Road = 1570 m

Table 2 presents the cyclic fatigue damage. Now one can determine the number of cycles that should be driven on proving grounds to reach the accumulated fatigue damage during the design life. The results have also been displayed in Table 2.

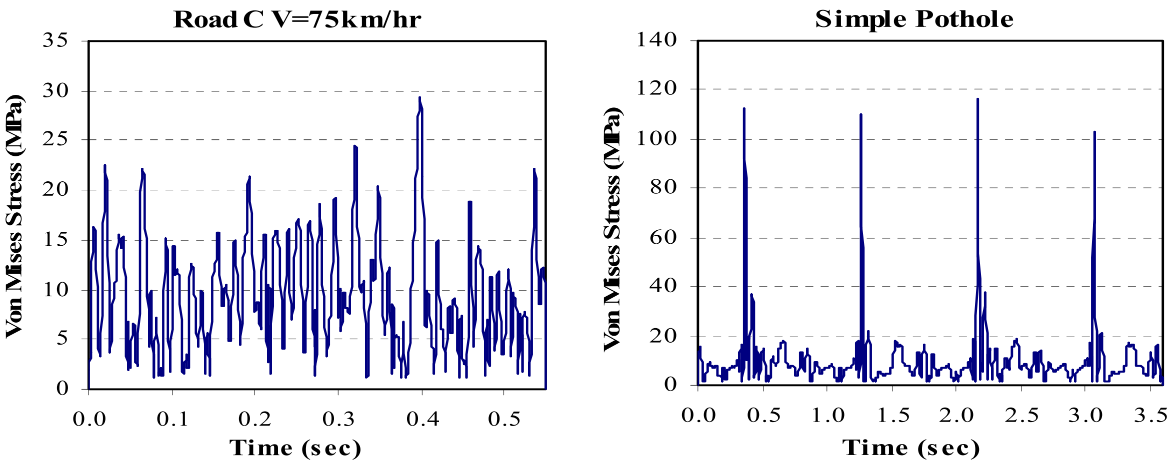


Fig. 11. Time history of Von-Mises stress in straight driving on road type C and simple pothole

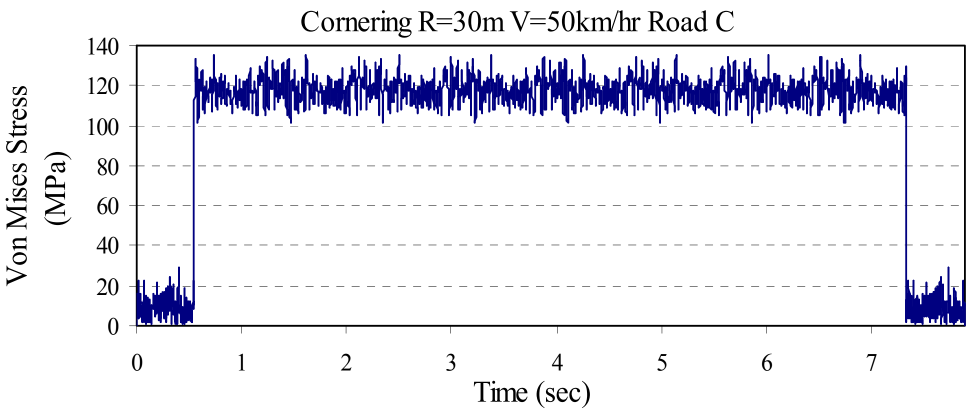


Fig. 12. Time history of Von-Mises stress in fast cornering cycle (straight- cornering- straight)

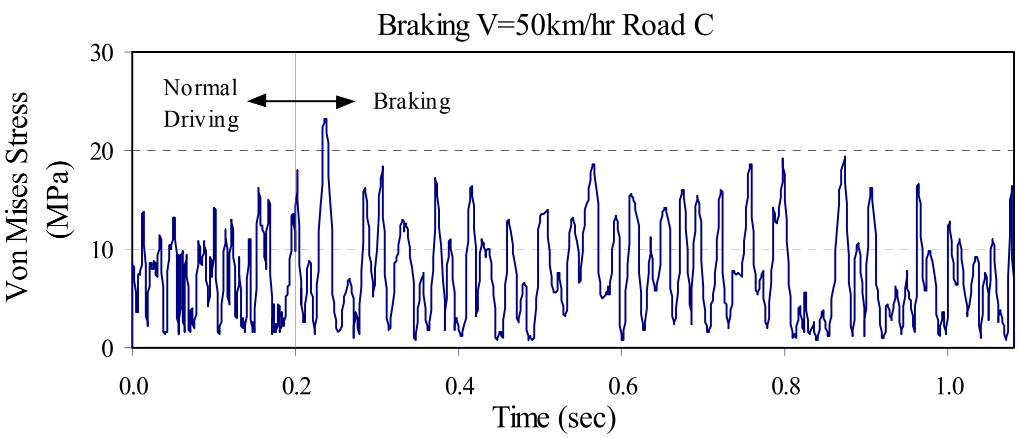


Fig. 13. Time history of Von-Mises stress in braking maneuver

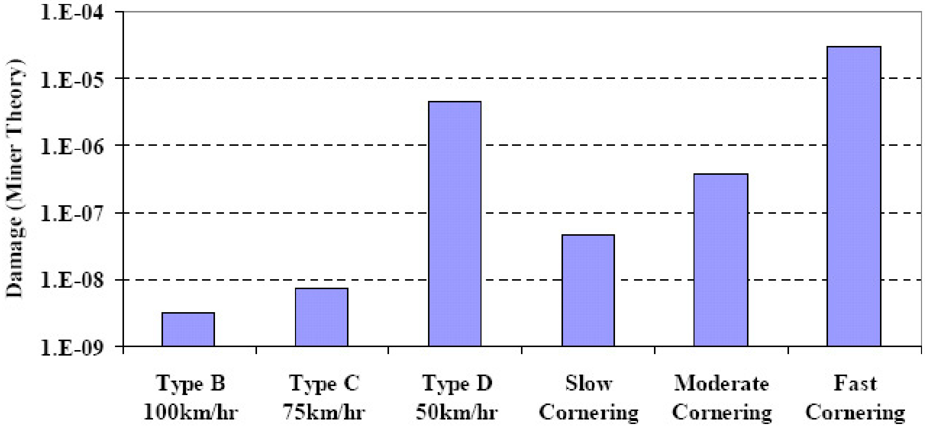


Fig. 14. Column chart of fatigue damage per kilometer of straight (three types), cornering and braking maneuvers

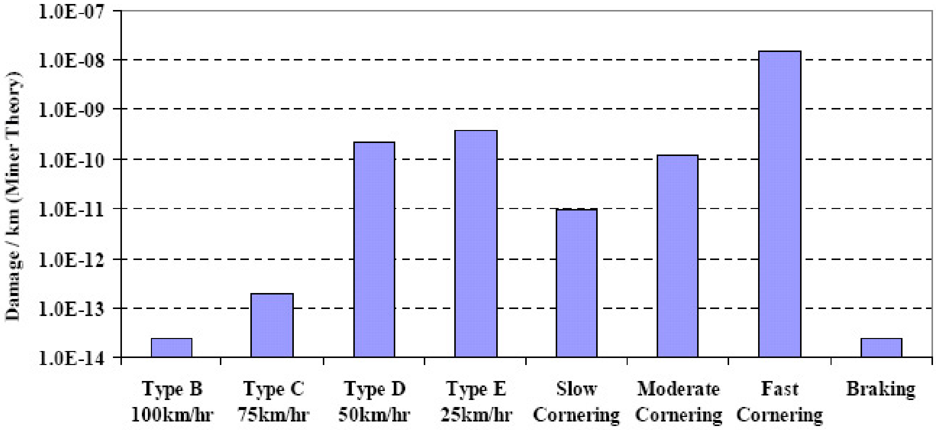


Fig. 15. Column chart of fatigue damage share of different maneuvers in 200000km driving

Table 1.
Fatigue damage per kilometer of proving ground events

Proving ground event	Oblique pothole	Simple pothole	Triangular pothole	Sine profile
Damage/km	2.9×10^{-8}	1.06×10^{-8}	2.26×10^{-8}	1.06×10^{-11}

Table 2.
Number of cycles of proving ground should be driven on to be equivalent to fatigue damage of actual driving in 200000 km

Equivalent road damage	One cycle of proving ground damage	Cycles of proving ground to reach damage of actual road
3.54E-05	2.26E-08	1568

7. Conclusions

The results showed that fast cornering has a greater damage effect than slow and moderate cornering. So the effect of slow and moderate cornering can be neglected. For braking, the fatigue damage effect was not more than that of normal straight driving. Of course there are some parts which bear high stress in braking maneuver. Comparing fast cornering with straight driving on rough roads (type D or E) and taking into account the occurrence percentages the damage in cornering was about five times higher than in straight driving. Therefore, it can be said that for primary evaluation of fatigue life (in our case) the cornering analysis is sufficient.

The proving ground events in comparison with the actual roads had a greater destructive effect on the fatigue damage accumulated in our test component. Driving 1568 cycles (2462 km) on the proving ground was equal to driving 200000 km on actual roads. It may be stated that the distance between the sequential events in the proving ground has a considerable effect on this equalization.

Acknowledgments

The authors would like to thank Sharif University of Technology for financial support, also to acknowledge AIRIC (Automotive Industries Research and Innovation Center), Mr. Mirabdolahi, Mr. Khorramizadeh and Mr. Shamsaei for their cooperation in this research.

References

[1] K. V. Smith, R. F. Stornant, Cumulative damage approach to durability route design, SAE 791033, 1979.

[2] F. Aslani, M. Yatheendar, R. H. Visintainer, D. S. Rohweder, J. L. de Alda, Simulation of proving ground events for heavy truck cabs using ADAMS,MSC/NASTRAN and P/FATIGUE", MSC 1994 World Users Conference Proceedings.

[3] Y. Zhang, A. Tang, T. Palmer, C. Hazard, Int. J. Vehicle Design, 21 (1999) 450-470.

[4] J. H. Canova, Vehicle design evaluation using the digital proving ground, SAE 2000-01-0126.

[5] J. Y. Wong, Theory of ground vehicles , John Wily & Sons, 1993

[6] MSC/NASTRAN Dynamic analysis handbook , Mac-Neal Swindler Corporation, 1994.

[7] J. A. Bannantine, J. J. Comer, J. L. Handrock, Fundamentals of metal fatigue analysis, Prentice Hall, 1990.

[8] Fatigue and fracture, ASM Handbook, Vol 19, ASM International, 1996.

[9] P/FATIGUE User manual, November 1990.

[10] SAE J1099, Technical report on low cycle fatigue properties ferrous and non-ferrous materials, 1998.

[11] P. Lukin, G. Gasparyants, V. Rodionov, Automobile chassis design and calculations, MIR Publisher, Moscow, 1989.