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Research on the Relationship Between the Stiffness of the Suspension of Cars and the Vibration Frequency of the Body

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Abstract: In the article, statistical descriptions of the set of values of the stiffnes and vibration frequencies of the suspension of 25 types of cars and their reliability limits were determined, checked the law of the empirical distribution and described them in graphs in the form of a distribution polygon. At the same time, a graphical description of the laws of the theoretical distribution was built, and a comparison with the distribution of the empirical graph was assessed on the norm of approximations and correspondence. At the same time, the correlation coefficient between the stiffness of the suspension and the vibration frequency of the bodies was determined.

Keywords: suspension stiffness, vibration frequency, empirical distribution, distribution range, approximations, correlation coefficient, fitness range.

Introduction

Today, the increasing need for cars is encouraging engineers to accelerate scientific research work on the development of new construction, technical and electronic solutions in various systems of the car in order to ensure the smoothness, stability of the car at low and high speeds in various road conditions [1]. One of the most significant areas of this research is the improvement of the suspension ridge of the car, a wide range of studies are also being carried out on this route. In the last decade, there have been rapid processes of globalization in the global economy and automotive industry. The world's largest automotive concerns and corporations began to play a significant role in the changes taking place in world industrial production. In 2023, the volume of the car suspension system on the world market was estimated at $ 45.45 billion. And in 2024, the growth rate of $ 47.25 billion is projected to be up to $ 107.12 billion by 2035, with an annual growth rate of 7.7 percent over the forecast period [2].

The development of suspension systems has long been one of the most significant issues of the automotive industry. The suspension performs several tasks, such as maintaining the connection between the car tires and the road, ensuring the stability of the vehicle and insulating the car body from vibrations and shocks at the expense of road irregularities. In general, walking fluency and stability are the most important factors in assessing the performance of the suspension system [3].

Including in Uzbekistan, in the current period, a policy of increasing the level of competitiveness of the country on the basis of technical and technological advances in the sectors of the real sector of the economy is being actively pursued. In this process, great importance is attached to mechanical engineering, in particular to the automotive industry, after all, the development of this industry is a symbol of the country's industrial development. Development of this area the tasks of development of scientific and applied research and innovation developments, modernization of production, application to technical and technological updating processes, ensuring a more solid connection of science and production, development of research and development work in priority segments of the production of spare parts and components are set out. This in turn necessitates the improvement of The Walking parts of light cars produced in our country as well [4, 5, 6, 7].

In this research work, an analysis of the parameters affecting the suspension elements was carried out when choosing the optimal values of the main parameters of the suspension system of light cars (stiffness, coefficient of resistance of the shock absorber, mass) to reduce the amplitude of car vibrations. In this case, the results of the experiment or the data obtained through measurement methods were processed statistically through special mathematical paths, studying the link between the stiffness coefficient of the suspension and the body's vibrational frequency.

Methods

The table below lists the values of the stiffness of the suspension and the vibration frequency of the body of 25 types of cars [8,9,10,11].

Table 1.

№	**Car brand**	**Stiffness of the suspension, *k*, N/mm**		**Vibrational frequency, *ν*, min^{-1}**	
		Front	**Rear**	**Front**	**Rear**
1	Alfa-Romeo Alfetta	22,6	22,1	87	86
2	Daimler-Benz-280 S	17,7	20,0	61	69
3	Ford granada 3000	14,2	18,1	58	71
4	Daimler-Benz -200	14,7	17,7	62	70
5	Opel-Rekord 11/1700	14,2	19,1	68	85
6	Ford Taunus 1600-Iks-L	13,0	22,9	64	108
7	Folswagen-1300	9,0	16,5	70	78
8	Folswagen -1303LS	8,3	17,5	63	80
9	Reno-6	12,7	12,8	57	78
10	Reno-15TS	12,6	14,4	62	85
11	Folswagen Passat LS	13,2	19,6	66	100
12	Audi 80 JL	12,8	16,7	65	95
13	Folswagen K70	14,7	16,7	65	84
14	Ford Taunus 600	13,3	22,0	67	101
15	Ford Kapri-I-2600	15,6	18,4	71	87
16	BMW turing 2000	19,5	17,3	65	76
17	Fiat 127	19,0	15,0	68	56
18	Sitroen –Ami-Super	19,0	10,1	70	56
19	VAZ-2106	20,0	15,0	83	71
20	VAZ-2101	14,2	18,6	64	96
21	VAZ-2121	16,6	17,8	72	83
22	GAZ 24-10	22,3	23,2	90	102
23	BMW 518	16,2	19,8	72	89
24	BMW 520	21,5	20,3	83	81
25	Reno-19	14,2	16,4	69	86

For statistical processing of results, we use the values given in Table 1.

The average arithmetic value of the variational series is determined from the formula below [12]

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \dots x_n}{n} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (1)$$

here n – number of variational series.

Mean quadratic deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \qquad (2)$$

Variation coefficient

$$V = \frac{\sigma}{\bar{x}} \cdot 100\% \qquad (3)$$

Table 2. Results obtained on preliminary statistical processing

№	Parameters	Stiffness of the suspension, N/mm		Vibrational frequency, min^{-1}	
		Front	**Rear**	**Front**	**Rear**
1	Average arithmetic value	15,6	17,9	68,9	82,9
2	Mean quadratic deviation	3,8	3,1	8,5	13,2
3	Variation coefficient %	23	17	12	16

We use the Student criterion to check the suspicious values inside the resulting results. The formula under the accounting value of the styling criterion is determined.

$$t_p = \left|\frac{x_i - \bar{x}}{\sigma}\right| \qquad (4)$$

here x_i – value perceived as questionable.

To test the skepticism of their values in the variational series, The method of the stylus is determined from the table that the degree of freedom of the series is t_T=2,064 when v=n-1=24, α=0,05. Also, if the value calculated from the ratio to the value of the stylus mezzanine in the table is small $t_p < t_T$, then the doubtful value is not considered a gross error.

Suspicious values between the values of the front suspension stiffness and the vibration frequency of the rear of the body: c_i=22,6; ν_i=108 turned out to $t_p < t_T$ when examined. Without exception, we take these values in a set and perform statistical processing. Suspicious values between the values of the rear suspension stiffness and the vibration frequency of the front of the body: c_i=10,1; ν_i=87; ν_i=90 turned out to be $t_p > t_T$ when checked. Then we remove these values from the set with the exception of statistical processing (formulas 1, 2, 3).

On the basis of the specified parameters, the bottom was determined:

The absolute error is determined by the following formula

$$\sigma_{ab} = \frac{\sigma_x}{\sqrt{n}} \qquad (5)$$

The relative error is equal to the ratio of the exact value of the absolute error

$$\sigma_{nis} = \frac{\sigma_{ab}}{\bar{x}} \cdot 100\% \qquad (6)$$

Table 3. Results obtained in statistical processing

№	Parametrlar	Stiffness of the suspension, N/mm		Vibrational frequency, min^{-1}	
		Front	**Rear**	**Front**	**Rear**
1	Average arithmetic value	15,6	18,2	67,2	82,9
2	Mean quadratic deviation	3,8	3,2	8,9	13,2

3	Variation coefficient %	24	15	9,6	16
4	Absolute error	0,76	0,65	1,85	2,64
5	Relative error, %	4,8	3,5	2,75	3,2

We determine the reliability limits of the head set for the front and rear suspension stiffness values, the average arithmetic value of the vibration frequencies, the average quadratic deviation. Reliability limits for front suspension stiffness values [13,14]:

When α=0,05 the Student criterion is used to define the limits of unemployment by the formula below

$$\bar{x} - t_{1-\frac{\alpha}{2}}\frac{\sigma_x}{\sqrt{n}} < m_x < \bar{x} + t_{1-\frac{\alpha}{2}}\frac{\sigma_x}{\sqrt{n}} \qquad (7)$$

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The reliability limits for the mean quadratic deviation are determined by the formula below

$$\sqrt{\frac{\sigma^2\nu}{\chi^2_{\alpha/2}}} < \sigma_x < \sqrt{\frac{\sigma^2\nu}{\chi^2_{1-\alpha/2}}} \qquad (8)$$

here-is the value of the Student coefficient $\left(1-\frac{\alpha}{2}\right)$ and ν is the probability $t_{1-\alpha/2}$ corresponding to the degree of freedom in the table; n is the number of variational row values; $\sigma^2 -$ is the dispersion; $\chi^2_{\alpha/2}$ and $\chi^2_{1-\alpha/2}$- $\left(1-\frac{\alpha}{2}\right)$ and values of the “x_i −square” distribution corresponding to $\frac{\alpha}{2}$.

Table 4. The result obtained in determining the statistical descriptions of the dataset and their reliability limits

№	**Parametrlar**	**Stiffness of the suspension, N/mm**				**Vibrational frequency, min^{-1}**			
		Front		**Rear**		**Front**		**Rear**	
1	Average arithmetic value	14,0	17,1	16,8	19,5	63,34	71,0	77,45	88,35
2	Mean quadratic deviation	2,95	5,26	2,48	4,49	6,86	12,6	10,26	18,40

We will examine the law of their distribution in terms of the stiffness of the suspension of 25 cars and the frequency of their displacement of the bodies for comparison, approximation and assessment by checking the law of the empirical distribution, as well as constructing a graphical description of the laws of the theoretical distribution. To do this, it is necessary to determine the *max* and *min* values of the stiffness values of the front suspension and determine their differences:

$$R = x_{max} - x_{min} \qquad (9)$$

here x_{max} and x_{min} − are the maximum and minimum values in the variational series.

To find the interval of values, we use the following expression

$$i = \frac{R}{k} \qquad (10)$$

here $k = \sqrt{n}$ −is the number of groups.

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№	**Parametrlar**	**Stiffness of the suspension, N/mm**		**Vibrational frequency, min^{-1}**	
		Front	**Rear**	**Front**	**Rear**
1	Variational row number of values, n	25	24	23	25
2	Maximum value in the variational series, x_{max}	22,6	23,2	83	108

3	Minimum value in the variational series, x_{min}	8,3	10,1	57	56
4	Difference between *max* and *min* values, R	14,3	13,1	26	52
5	Number of groups, k	5	4,89≈5	4,79≈5	5
6	Price range, i	3	2,6	6,6	10,4

Results and Discussion

Based on the results of the calculation, we build graphs of the distribution polygon (Figures 1, 2, 3, 4), sorting out the stiffness of the front and rear suspension and the front and rear of the body by the given values of the vibration frequency.

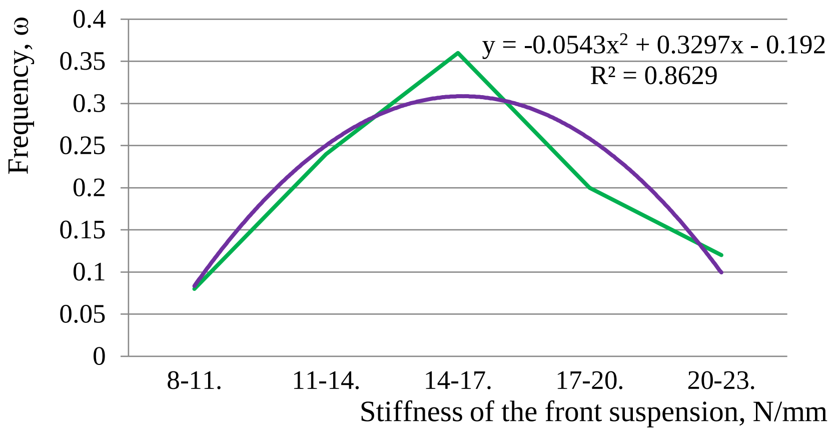

Figure 1. The law of the empirical distribution of the stiffness of the front suspension is the distribution polygon

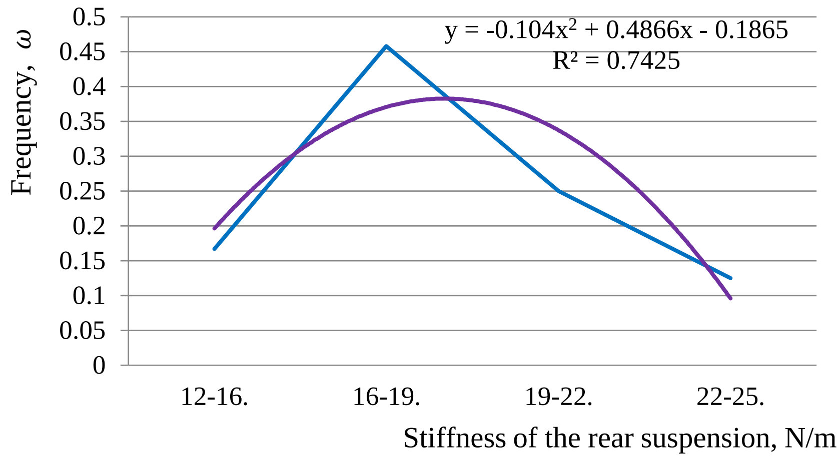

Figure 2. The stiffness of the back suspension is defined by the law of the empirical distribution of the distribution Polygon

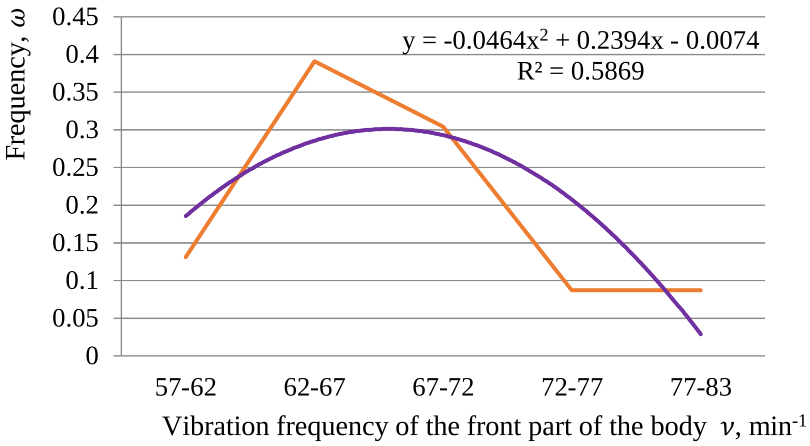

Figure 3. Frequency of oscillation of the front of the body is the law of the empirical distribution of the distribution range

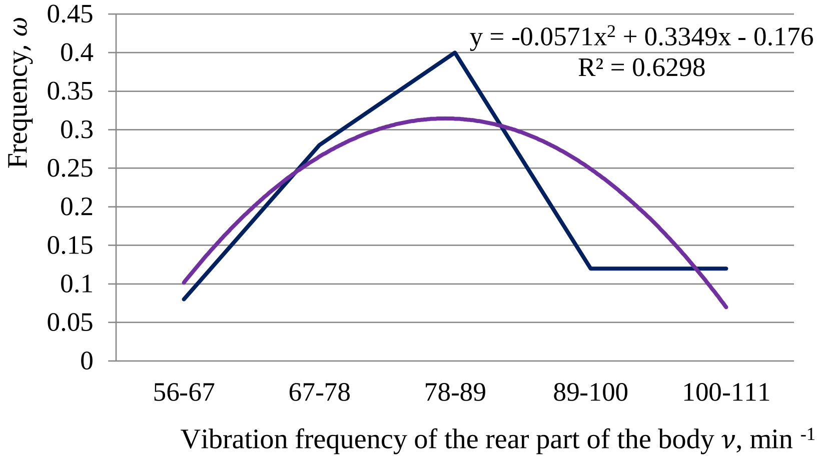

Figure 4. Frequency of vibration of the rear of the body is the law of the empirical distribution of the distribution range

Based on the results obtained from the analysis of scientific works, the correlation coefficients between the stiffness value of the front suspension and the values of the vibration frequency of the front of the body are calculated, for which a correlation table is initially drawn up based on experimental data.

Table 6. Correlation table of the values of the stiffness of the front suspension and the values of the vibration frequency of the front of the body

Y(ν_{fr})	X (c_{fr})					n_y	$y_j n_y$	$y^2_j n_y$	$x_i n_{yx}$	$y_j x_i n_{yx}$	№
	8,70	***12,90***	***14,90***	***19,00***	***22,10***						
59	0	1	1	1	0	3	177	10443	46,8	2761,2	1
64	1	5	3	1	0	10	576	36864	124	7936	2
69	1	1	3	2	0	7	483	33327	104,3	7196,7	3
72	0	0	2	0	0	2	144	10368	29,8	2145,6	4
83	0	0	0	1	1	2	166	13778	41,1	3411,3	5
n_x	2	7	9	5	1	24	1546	104780	346	23450, 8	6
$x_i n_x$	17,4	77,4	134,1	95	22,1	346					7
$x^2_i n_x$	151,38	998,5	1998,1	1805	488,4	5441,3 4					8
$y_i n_{yx}$	133	384	602	344	83	1546					9
$x_i y_i n_{yx}$	1157,1	4953,6	8969,8	6536	1834,	23450,					10

					3	8					
№	1	2	3	4	5	6	7	8	9	10	

Table 6. Correlation table of the values of the stiffness of the rear suspension and the values of the vibration frequency of the rear of the body

$Y(\nu_{re})$	X (c_{re})				n_y	$y_j n_y$	$y^2_j n_y$	$x_i n_{yx}$	$y_j x_i n_{yx}$	№
	14,30	***17,40***	***20,10***	***22,70***						
56	1	0	0	0	1	56	3136	14,3	800,8	1
73,2	2	4	1	0	7	512,4	37507,68	118,3	8659,56	2
84,6	1	5	3	1	10	846	71571,6	184,3	15591,8	3
97	0	2	1	0	3	291	28227	54,9	5325,3	4
103,6	0	0	1	2	3	310,8	32198,88	65,5	6785,8	5
n_x	4	11	6	3	24	2016,2	172641,2	437,3	37163,2	6
$x_i n_x$	57,2	191,4	120,6	68,1	437,3					7
$x^2_i n_x$	817,96	3330,36	2424,06	1545,87	8118,25					8
$y_i n_{yx}$	287	909,8	527,6	291,8	2016,2					9
$x_i y_i n_{yx}$	4104,1	15830,52	10604,76	6623,86	37163,2					10
№	1	2	3	4	5	6	7	8	9	

Using the results in table 6 and 7, the correlation coefficient is determined by the expression below,

$r_p=\frac{\overline{xy}-\bar{x}\cdot\bar{y}}{\sigma_x\cdot\sigma_y}$ (12)

here $\bar{x}=\frac{1}{n}\sum_{i=1}^{p}x_i n_x$; $\bar{y}=\frac{1}{n}\sum_{i=1}^{k}y_j n_y$; $\overline{xy}=\frac{1}{n}\sum_{i=1(j=1)}^{p(k)}x_i y_j n_{xy}$;

$\sigma_x=\sqrt{\frac{1}{n}\sum_{i=1}^{p}x_i^2 n_x-\bar{x}^2}$; $\sigma_y=\sqrt{\frac{1}{n}\sum_{i=1}^{k}y_i^2 n_x-\bar{y}^2}$.

The mean error of the correlation coefficient is determined by the mean of the expression below

$r_\sigma=\frac{1-r_p^2}{\sqrt{n}}$ (13)

The correlation is calculated below the final value of the coefficient

$r=r_p\pm r_\sigma$ (13)

Table 8. The results of the calculations made on the determination of the coefficient of stiffness of the front and rear suspension and the correlation between the vibration frequencies of the body

№	Parameters under comparison	Correlation coefficient r_p	Mean error coefficient of correlation r_σ	The actual value of the correlation coefficient, r
1	Stiffness of the front suspension (c_{fr}) and vibration frequency of the front part of the body (ν_{fr})	0,43	0,17	$0{,}43\pm0{,}17$
2	Stiffness of the rear suspension (c_{re}) and vibration frequency of the rear part of the body (ν_{re})	0,24	0,19	$0{,}24\pm0{,}19$

In addition to analytical calculations, the Excel program also carried out research on correlation coefficient determination, and the laws of correlation between two pairs of variational series were built [15].

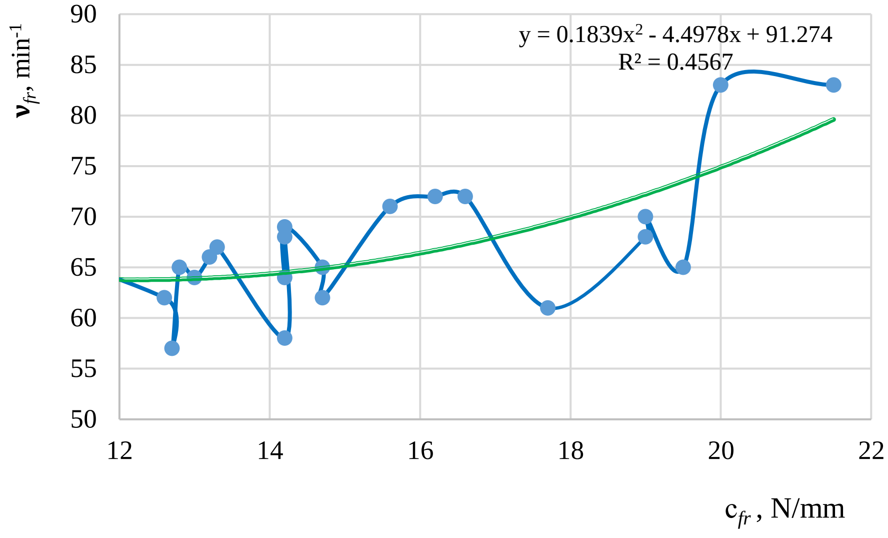

Figure 9. Graph of the law of connection between the stiffness of the front suspension (c_{fr}) and the vibration frequency (ν_{fr}) of the front of the body

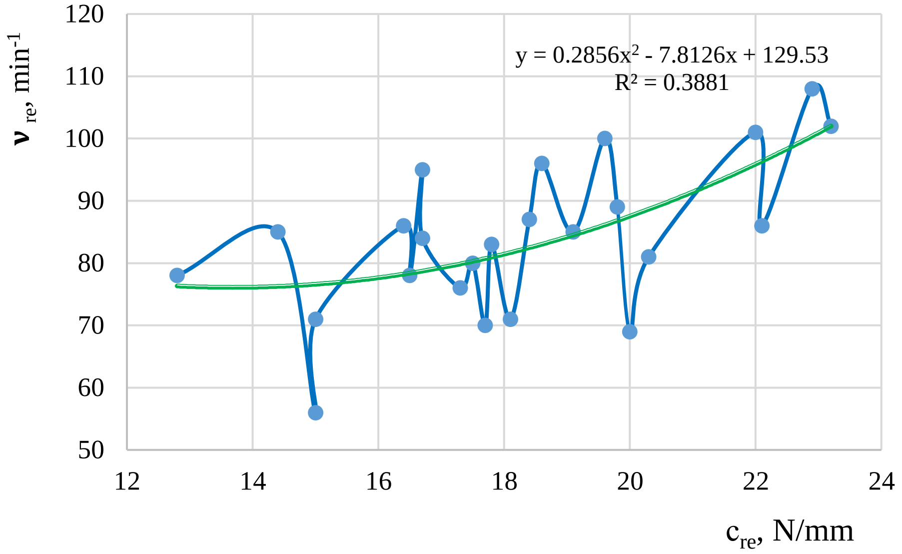

Figure 10. Graph of the law of connection between the stiffness of the front suspension (c_{re}) and the vibration frequency (ν_{re}) of the front of the body

Conclusion

Conclusion. According to the results of preliminary statistical processing of cars of the cited brand on the stiffness of the front suspension and the vibration frequency of the front of the body, it was found that the data are subject to the law of Normal distribution. When approximated and evaluated on the compatibility criterion, the compatibility coefficient was found to be R^2=0,58-0,84 (figures 1,2,3,4). At the same time, based on the correlation analysis of the parameters, it was found that the correlation coefficient between the stiffness of the front suspension and the vibration frequency of the front of the body is 0,4567, and the coefficient between the stiffness of the rear suspension and the vibration frequency of the rear of the body is 0,3881. Since the correlation coefficient is $r<0,5$ the bond between them is weak. But the suspension is the main system connecting the body with the car wheel, absorbing some of the shocks generated from road irregularities when the car moves, initially by adopting the wheel tire and the main part by the suspension. With this in mind, the vibration of the car body will largely depend on the suspension biker.

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