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# Sensitivity analysis of structures and environmental parameter for the speed limits of the car running on the corroded steel girder bridge over time

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ABSTRACT

The speed limit is an important parameter in reducing traffic accidents and advancing traffic works life. The steel girder bridge is a structure widely used in road and rail traffic works. However, the steel girder bridge service life is highly dependent on loads, speed limit, and environmental parameters. This paper presents the sensitivity analysis of structural and environmental parameters for the speed limit of the car running on the corroded steel girder bridges over time. To achieve research objectives: An analytical model based on resonance theory has been built to determine the speed limits. The global sensitivity analysis method based on Sobol's sensitivity indices with Monte-Carlo simulation was used to evaluate the effect of the parameters. Corrosion model and form corrosion of corroded steel girder bridge were used in the previous proposal. Finally, the effects of the structural and environmental parameters on the speed limits of the corroded steel girder bridge about 20-years, 30-years, 50-years, and 100- years has been presented.


## 1. Introduction

The speed limits are a very important topic in ensuring traffic safety as well as improving the traffic works life. In particular, the traffic works life has been degrading due to environmental factors. Steel girders bridge were a type of structure widely used in traffic works. However, the speed limit considering metal corrosion has not been paid enough attention to.

Metal corrosion is a complex process, and a topic attracted many scientists in the world. The metal corrosion process is often modeled into mathematical expressions. One of them, the metal corrosion model proposed by Komp was a general model for many different types of environments [1]. R. Landolfo *et al* published a report on damage modeling due to corrosion of metal structures [2]. Meanwhile, M. Seccer *et al* has been used the M.E. Komp to investigate the corrosion failure of steel frames considering lateral bending [3]. Applying the corrosion model of M.E. Komp for reinforced concrete-steel composite girder structure considering the decline in reliability after 100 years combined with the overall sensitivity analysis method published by NT Ha et al in [4]. In addition, reliability analysis problems that consider the effects of corrosion are published in [5–7].

Global sensitivity analysis based on Sobol's sensitivity indices was proposed by Ilya M. Sobol, he is a Russian mathematician. Global sensitivity analysis has been shown most accurately the effect of input parameters (variable). Nowadays, global sensitivity analysis has been widely applied. In 2020, T.H Nguyen *et al* had applied the global sensitivity analysis on the effect of input parameters for the buckling of steel arch [8]. Z. Kala *et al* had applied this method to a series of studies on structural steel [9,10]. Meanwhile, in 2011 J. Morio had proposed to use the global sensitivity analysis for a physical system [11]. In 2020, the evaluation and influence of the corroded steel–concrete composite beam structural parameters by the global sensitivity and reliability analysis method had proposed by T.H Nguyen *et al* [4].

However, to the knowledge of the author, there was not any research applying global sensitivity analysis based on Sobol's sensitivity indices to evaluate the influence of the input parameters for speed limit running on corroded steel girder bridges. Meanwhile, the steel girder bridge has service life is highly dependent on loads, speed limit, and environmental parameters. Therefore, this paper

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will be applying the global sensitivity analysis method based on Sobol's sensitivity indices to evaluate the influence of the input parameters on the speed limits running on corroded steel girder bridges. This result will be helped designers and managers to service life and reduce traffic accidents.

## 2. Theoretical background

### *2.1. Determine the speed limits model based on resonance theory*

Consider a car running on the steel girder bridge has parameters: the car's weight (*M*) and tire diameter (*DC*), and steel girder bridge has structural parameters including top flange (TF), the thickness of top flange (*t-TF*), bottom flange (BF), bottom flange thickness (*t-BF*), girder height (*D*), web thickness (*t-w*) and the span of girder (*L*) is shown in Fig. 1 and Fig. 2.

The speed limit calculation model of the car running on the steel girder bridge in time (*t*) can be modelled by the diagram as shown in Fig. 2.

Consider the steel girder bridge subjected to movable loads has the form $P(t) = P + G\sin rt$ as shown in Fig. 3. The differential equation of girder oscillation at the position between has the form.

$$y''(t) + \omega^2 y(t) = \omega^2 \delta_{11}(P + G\sin rt)\sin\theta t \tag{1}$$

The solution left of Eq. (1) has the form:

$$y(t) = A\sin\omega t + B\cos\omega t + \frac{P\delta_{11}\sin\theta t}{1 - \theta^2/\omega^2} \tag{2}$$

else

$$y(t) = A\sin\omega t + B\cos\omega t + \frac{2P}{ml}\frac{\sin\theta t}{\omega^2 - \theta^2} \tag{3}$$

where, $\omega^2 = \frac{1}{M\delta_{11}}$ is natural frequency of the girder; $m$ is the mass of the girder; $\delta_{11} = \frac{l^3}{48EI}$ is the static displacement of the mass set point caused by $P = 1.0$.

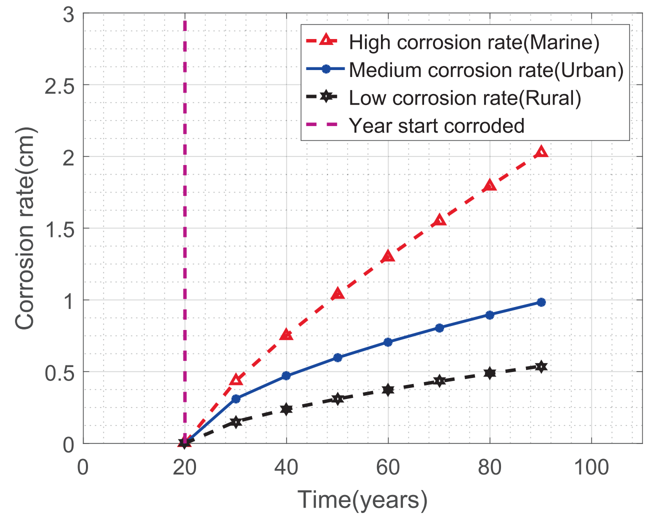


**Fig. 3.** The flowchart corrosion rate of the environment.

Transform the right of the Eq. (1), as follows

$$\omega^2\delta_{11}G\sin rt\sin\theta t = \frac{2G}{ml}\sin rt\sin\theta t = \frac{G}{ml}(\sin\varphi_1 t + \sin\varphi_2 t) \tag{4}$$

Here, $\varphi_1 = r - \theta$; $\varphi_2 = r + \theta$; $\theta = \frac{\pi v}{l}$Rewrite Eq. (1) as follows

$$y''(t) + \omega^2 y(t) = \frac{G}{ml}(\sin\varphi_1 t + \sin\varphi_2 t) \tag{5}$$

The solution of the differential Eq. (5) has the form

$$y(t) = \frac{G}{ml}\left(\frac{\cos\varphi_1 t}{\omega^2 - \varphi_1^2} + \frac{\cos\varphi_2 t}{\omega^2 - \varphi_1^2}\right) \tag{6}$$

Combining Eqs. (3) and (6) the static displacement of the mass set point is shown below.

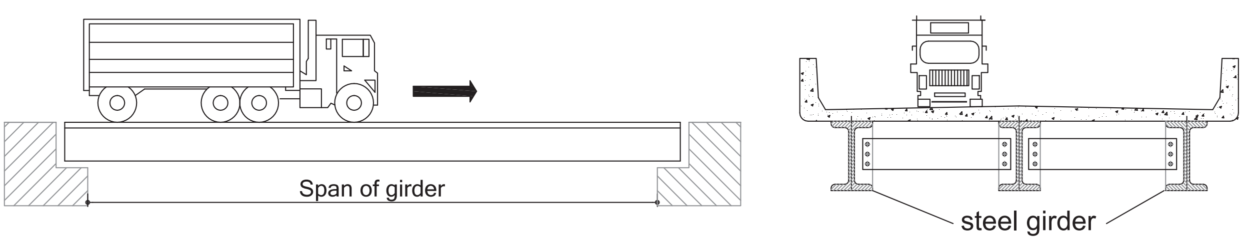


**Fig. 1.** A car running on the steel girder bridge.

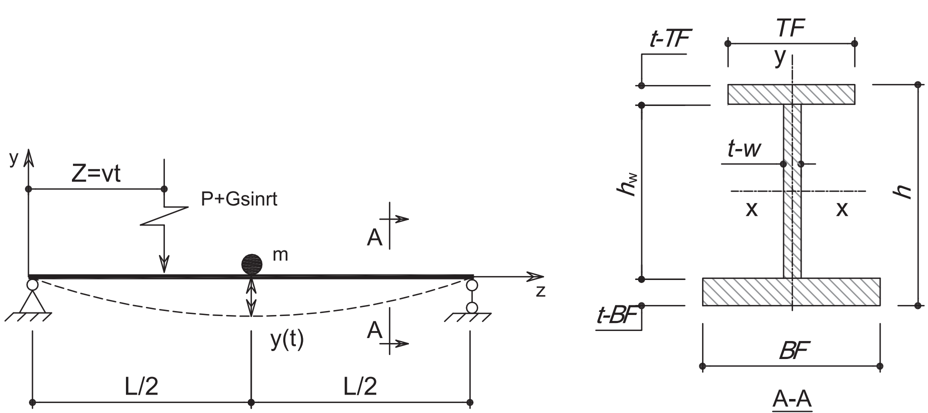


**Fig. 2.** Calculation model of the car running on the bridge.

$$y(t) = A\sin\omega t + B\cos\omega t + \frac{2P}{ml}\frac{\sin\theta t}{\omega^2-\theta^2} + \frac{G}{ml}\left(\frac{\cos\varphi_1 t}{\omega^2-\varphi_1^2} + \frac{\cos\varphi_2 t}{\omega^2-\varphi_1^2}\right) \quad (7)$$

Where, $A$ and $B$ are integral constants defined at $t=0$ then $y(0)=0$; $y'(0)=0$. Respectively. After finding $A$ and $B$ the Eq. (7) is rewritten in the form.

$$y(t) = \frac{2P}{ml(\omega^2-\theta^2)}\left(\sin\theta t - \frac{\theta}{\omega}\sin\omega t\right) + \frac{G(\cos\varphi_2 t - \cos\omega t)}{ml(\omega^2-\varphi_1^2)} + \frac{G(\cos\varphi_2 t - \cos\omega t)}{ml(\omega^2-\varphi_2^2)}. \quad (8)$$

From Eq. (8), resonance will occur in the following cases

Case study $1\omega = \theta$

Case study $2\omega = \varphi_i (i = 1,2)$

We have $\omega = \frac{2v_{th}}{DC} \pm \frac{\pi v_{th}}{l}$

The speed limits for the case of the movable loads consider the eccentric mass of the car running on the bridge.

$$v_{th} = \frac{\omega}{\frac{2}{DC} \pm \frac{\pi}{l}} where\, \omega = \frac{\pi^2}{l^2}\sqrt{\frac{EI}{m}} \quad (9)$$

The speed limits minimum value is determined

$$v_{th(\min)} = \frac{\omega}{2/DC + \pi/l} \quad (10)$$

where, $DC$ is tire diameter of the car.

The speed limits calculation model has been set up. The study has conducted programming to calculate speed limit value for car running on the steel girder bridge ($V_{th(min)}$) with input parameters including the car's weight ($M$) and tire diameter ($DC$), and the steel girder bridge has structural parameters including top flange ($TF$), top flange thickness ($t$-$TF$), bottom flange ($BF$), bottom flange thickness ($t$-$BF$), girder height ($D$), web thickness ($t$-$w$) and the span of girder ($L$) based on MATLAB programming for data generation in the next step.

### 2.2. Corrosion models

In this study, corrosion parameters such as structural, section deterioration, form corrosion, and fatigue strength have been used as suggested in [12]. While the unprotected carbon steel corrosion rate in the atmosphere obeys an exponential law formula, the dependent parameters and environmental conditions have been determined in [1].

**Table 1**
Coefficient $\Delta_A$ and $\Delta_B$ of the environment [1].

| Environment | Carbon steel | |
|---|---|---|
| | $\Delta_A$ | $\Delta_B$ |
| Rural | 34.0 | 0.65 |
| Urban | 80.2 | 0.59 |
| Marine | 70.6 | 0.79 |

$$R(t) = \Delta_A t^{\Delta_B} \quad (11)$$

where, $R(t)$ is the average corrosion rate ($\mu m$); $t$ is the time of metal was unprotected (years). $\Delta_A$ and $\Delta_B$ are parameters determined from local experimental data [1]. There are three environments including marine environment, urban environment, rural environment, corresponding to the corrosion rate (high, medium, low) shown in Table 1.

In this study, effective protective coating assumes for 20 years (zero corrosion rate). The corrosion rate in unprotected conditions was determined starting from 20th years, so the corrosion rate diagram was adjusted and shown in Fig. 3.

The form-corrosion that has occurred to the steel girders bridge is based on statistics had proposed in [12] and as shown in Fig. 4.

### 2.3. Global sensitivity analysis

Global sensitivity analysis based on Sobol's sensitivity indices was proposed by Ilya M. Sobol, he is a Russian mathematician. Global sensitivity analysis has been shown most accurately the effect of input parameters (variable) $X = (X_1, X_2, ..., X_m)$ on the output function $Y = f(X)$. Here, $X = (X_1, X_2, ..., X_m)$ is the design parameters vector, and $Y = (Y_1, Y_2, ..., Y_n)$ is the output vector, in space $\mathbb{R}^{\mathbf{m}}$.

Considering output integrable function $Y = f(X)$ on the space $[0,\ 1]^n$ with input variables $X_i$, where, $X_i$ are the random independent variables on the space $[0,\ 1]^m$. $Y = f(X)$ can be decomposed into elementary functions [11]

$$f(X) = f_0 + \sum_i f_i(X_i) + \sum_{i<j} f_{ij}(X_i, X_j) + \cdots + f_{1\cdots m}(X_1, ..., X_m) \quad (12)$$

where, $f_0$ is a constant; these functions satisfy the condition.

$$\int_0^1 f_{i_1...i_s}(x_{i_1}, ..., x_{i_s})dx_k = 0 \,\text{with}\, k = i_1, ..., i_s$$

and

$$\int_0^1 f_{i_1...i_s}(x_{i_1}, ..., x_{i_s}) f_{j_1..j_t}(x_{j_1}, ..., x_{j_t})dx = 0 \quad (14)$$

With $\forall k \in \{1, ..., n\}$ and $\{i_1, ..., i_s\} \subseteq \{1, ..., n\}$. From Eq. (12) with input independent variables $X_i$, the output variance $Y = f(X)$ was determined by.

$$Var[Y] = \sum_{i=1}^{m} V_i + \sum_{1\leqslant i<j\leqslant m}^{m} V_{ij} + ... + V_{1...m} \quad (15)$$

Here,

$$V_i = Var[E[Y|X_i]]$$

$$V_{ij} = Var\left[E[Y|X_iX_j]\right] - V_i - V_j$$

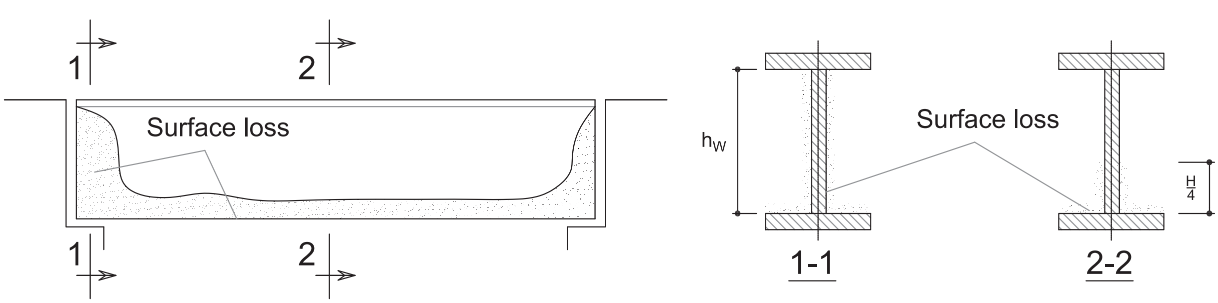


**Fig. 4.** Form-corrosion of steel girders bridge (). adapted from [12]

$$V_{1\dots n} = Var[Y] - \sum_{i=1}^{m} V_i - \sum_{1\leqslant i<j\leqslant m}^{m} V_{ij} - \sum_{1\leqslant i_1<\dots<i_{n-1}\leqslant m}^{m} V_{i_1\dots i_{m-1}}$$

The first-order Sobol's sensitivity indices show the individual effect of input parameters $X_i$ on the output parameter, which determined by the following equation.

$$S_i = \frac{V_i}{Var[Y]} \quad (16)$$

The second-order Sobol's sensitivity indices show interaction effect of two parameters $X_i$ and $X_j$ on the output parameter, which determined by the following equation.

$$S_{ij} = \frac{V_{ij}}{Var[Y]} \quad (17)$$

The total-order Sobol's sensitivity indices show individual and interaction effect of the input parameters on the output parameter, which determined by the following equation.

$$S_{Ti} = S_i + S_{ij} + S_{ikl} + \dots + S_{i\dots n} \quad (18)$$

The Sobol's sensitivity indices in the Eqs. (16), (17), and (18) were determined estimated by the Monte Carlo method [13,14]. Consider 2 $N$ – sample-size realization of $X$ shown in equation.

$$\widetilde{X}_k^j = \left(x_{k1}^j, \dots, x_{km}^j\right)_{k=1,\dots N, j=1,2} \quad (19)$$

The first-order Sobol's sensitivity indices of $X$ determined by the following equation.

$$\widehat{S}_i = \frac{\widehat{V}_i}{\widehat{V}} = \frac{\widehat{U}_i - \widehat{f}_0^2}{\widehat{V}}, \ where \widehat{f}_0 = \frac{1}{N}\sum_{k=1}^{N} f\left(x_{k1}^1, \dots, x_{km}^1\right) \quad (20)$$

Simulation of variance is determined by

$$\widehat{V} = \frac{1}{N}\sum_{k=1}^{N} f^2\left(x_{k1}^1, \dots, x_{km}^1\right) - \widehat{f}_0^2 \quad (21)$$

And $\widehat{U}_i$ was obtained using 2 N samples of $X$ as follows.

$$\widehat{U}_i = \tfrac{1}{N}\textstyle\sum_{k=1}^{N} f\left(x_{k1}^1, \dots, x_{k(i-1)}^1, x_{ki}^1, x_{k(i+1)}^1, \dots, x_{km}^1\right) \times \times f\left(x_{k1}^2, \dots, x_{k(i-1)}^2, x_{ki}^1, x_{k(i+1)}^2, \dots, x_{km}^2\right). \quad (22)$$

The second-order Sobol's sensitivity indices of $X$ determined by the following equation.

$$\widehat{S}_{ij} = \frac{\widehat{U}_{ij} - \widehat{f}_0^2 - \widehat{V}_i - \widehat{V}_j}{\widehat{V}} \quad (23)$$

where,

$$\widehat{U}_{ij} = \tfrac{1}{N}\textstyle\sum_{k=1}^{N} f\left(x_{k1}^1, \dots, x_{k(i-1)}^1, x_{ki}^1, x_{k(i+1)}^1, \dots, x_{k(j-1)}^1, x_{kj}^1, x_{k(j+1)}^1, \dots, x_{km}^1\right) \times f\left(x_{k1}^2, \dots, x_{k(i-1)}^2, x_{ki}^1, x_{k(i+1)}^2, \dots, x_{k(j-1)}^2, x_{kj}^1, x_{k(j+1)}^2, \dots, x_{km}^2\right) \quad (24)$$

The total-order Sobol's sensitivity indices of $X$ determined by the following equation.

$$\widehat{S}_{Ti} = 1 - \frac{\widehat{U}_i - \widehat{f}_0^2}{\widehat{V}} \quad (25)$$

with

$$\widehat{U}_{\tilde{i}} = \tfrac{1}{N}\textstyle\sum_{i=1}^{N} f\left(x_{k1}^1, \dots, x_{k(i-1)}^1, x_{ki}^1, x_{k(i+1)}^1, \dots, x_{km}^1\right) \times f\left(x_{k1}^1, \dots, x_{k(i-1)}^1, x_{ki}^2, x_{k(i+1)}^1, \dots, x_{km}^1\right) \quad (26)$$

In this research, the Sobol's sensitivity indices with Monte Carlo simulation established MATLAB. This computer program has been verified through the sensitivity analysis of the ISHIGAMI function, the results obtained are reliable [8,15].

## 3. Effect of the input parameter on the speed limits

In this section, the effect of structural and environmental parameters has been evaluated on the speed limits of the car running on the corroded steel girder bridge, the speed limit has been determined the expression (18). The time selected for the assessment was 20-years (excluding corrosion), 30-years, 50-years, and 100-years. Input values and probability distributions of structures and environment parameters are shown in Table 2.

### *3.1. Effect of input parameters on the speed limit after 20-years corrosion*

Effect of input parameters on the speed limit of the car running on the corroded steel girder bridge after 20-years was the assessment by global sensitivity analysis based on the Sobol's sensitivity indices. The influence of random input parameters with the 200,000 Monte-Carlo simulations are shown in Table 3 and Fig. 5. Can be see that the first and total order Sobol's sensitivity have not a big difference.

**Table 3**
Mean estimation of first and total sensitivity Sobol's indices with 200,000 Monte-Carlo simulation.

| Variable | 1st sensitivity Sobol' indices | Total sensitivity Sobol' indices |
|---|---|---|
| $X_1$ (*TF*) | 0.0447 | 0.0426 |
| $X_2$ (*t-TF*) | 0.0250 | 0.0196 |
| $X_3$ (*BF*) | 0.0234 | 0.0216 |
| $X_4$ (*t-BF*) | 0.0096 | 0.0062 |
| $X_5$ (*D*) | 0.0937 | 0.0954 |
| $X_6$ (*t-W*) | 0.1052 | 0.0954 |
| $X_7$ (*M*) | 0.0440 | 0.0428 |
| $X_8$ (*DC*) | 0.1463 | 0.1473 |
| $X_9$ (*L*) | 0.6260 | 0.6317 |

**Table 2**
Input parameters for global sensitivity analysis.

| Properties | Units | Symbol | Distribution | Range |
|---|---|---|---|---|
| Structures | *cm* | $X_1$ (*TF*) | Uniform | 38.7–47.3 |
| | *cm* | $X_2$ (*t-TF*) | Uniform | 4.5–5.5 |
| | *cm* | $X_3$ (*BF*) | Uniform | 35.1–42.9 |
| | *cm* | $X_4$ (*t-BF*) | Uniform | 3.6–4.4 |
| | *cm* | $X_5$ (*D*) | Uniform | 62.1–75.9 |
| | *cm* | $X_6$ (*t-W*) | Uniform | 4.5–5.5 |
| | *kG* | $X_7$ (*M*) | Uniform | 4644.9–5677.1 |
| | *cm* | $X_8$ (*DC*) | Uniform | 71.1–86.9 |
| | *cm* | $X_9$ (*L*) | Uniform | 1764.9–2157.1 |

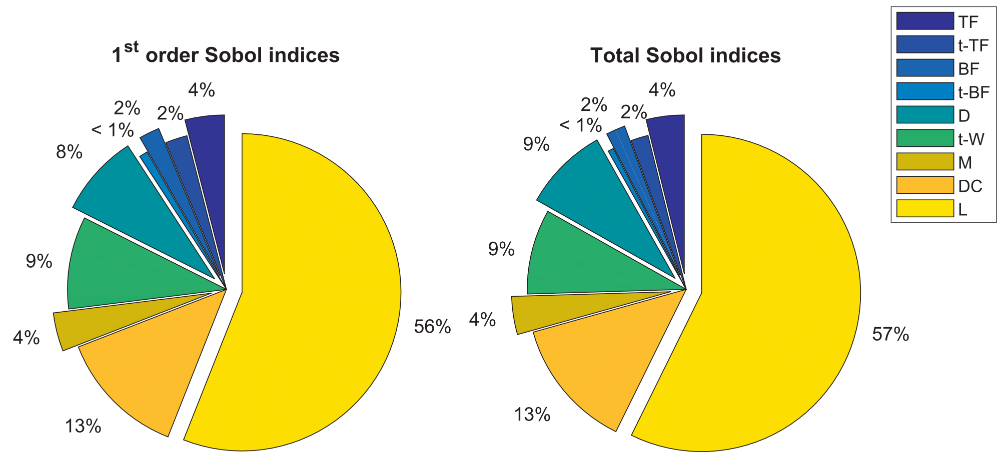


**Fig. 5.** First and total order Sobol's sensitivity indices of the corroded steel girder bridge at the 20-years.

### 3.2. Effect of input parameters on the speed limit after 30-years corrosion

Effect of input parameters on the speed limit of the car running on the corroded steel girder bridge after 30-years was the assessment by global sensitivity analysis based on the Sobol's sensitivity indices. The influence of random input parameters with the 200,000 Monte-Carlo simulations are shown in Table 4 and Fig. 6.

### 3.3. Effect of input parameters on the speed limit after 50-years corrosion

Effect of input parameters on the speed limit of the car running on the corroded steel girder bridge after 50-years was the assessment by global sensitivity analysis based on the Sobol' sensitivity indices. The influence of random input parameters with the 200,000 Monte-Carlo simulations are shown in Table 5 and Fig. 7.

**Table 4**
Mean estimation of first and total sensitivity Sobol's indices with 200,000 Monte-Carlo simulation.

| Variable | 1st sensitivity Sobol' indices | Total sensitivity Sobol' indices |
|---|---|---|
| $X_1$ (*TF*) | 0.0426 | 0.0414 |
| $X_2$ (*t-TF*) | 0.0187 | 0.0184 |
| $X_3$ (*BF*) | 0.0269 | 0.0229 |
| $X_4$ (*t-BF*) | 0.0070 | 0.0054 |
| $X_5$ (*D*) | 0.0952 | 0.0943 |
| $X_6$ (*t-W*) | 0.0990 | 0.0943 |
| $X_7$ (*M*) | 0.0445 | 0.0431 |
| $X_8$ (*DC*) | 0.1452 | 0.1493 |
| $X_9$ (*L*) | 0.6280 | 0.6394 |

**Table 5**
Mean estimation of first and total sensitivity Sobol's indices with 200,000 Monte-Carlo simulation.

| Variable | 1st sensitivity Sobol' indices | Total sensitivity Sobol' indices |
|---|---|---|
| $X_1$ (*TF*) | 0.0413 | 0.0380 |
| $X_2$ (*t-TF*) | 0.0183 | 0.0151 |
| $X_3$ (*BF*) | 0.0312 | 0.0249 |
| $X_4$ (*t-BF*) | 0.0053 | 0.0021 |
| $X_5$ (*D*) | 0.0951 | 0.0903 |
| $X_6$ (*t-W*) | 0.0951 | 0.0903 |
| $X_7$ (*M*) | 0.0438 | 0.0425 |
| $X_8$ (*DC*) | 0.1485 | 0.1471 |
| $X_9$ (*L*) | 0.6211 | 0.6280 |

### 3.4. Effect of input parameters on the speed limit after 100-years corrosion

Effect of input parameters on the speed limit of the car running on the corroded steel girder bridge after 100-years was the assessment by global sensitivity analysis based on the Sobol' sensitivity indices. The influence of random input parameters with the 200,000 Monte-Carlo simulations are shown in Table 6 and Fig. 8. Can be seen that the first and total order Sobol's sensitivity

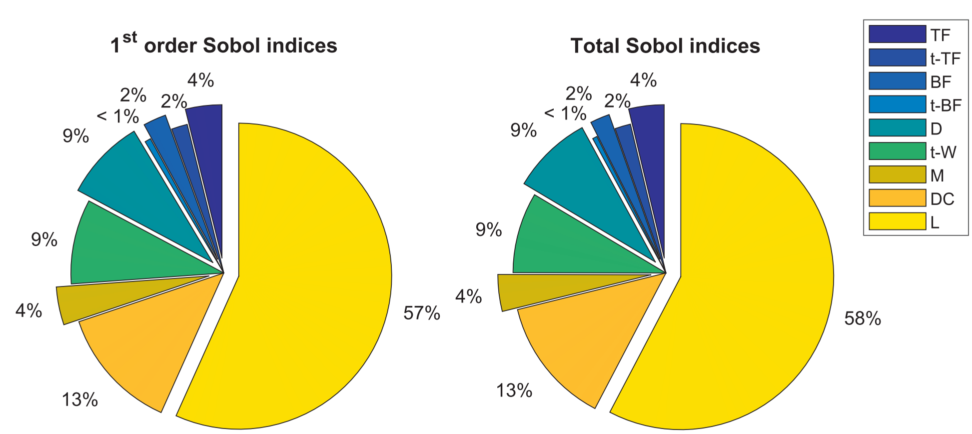


**Fig. 6.** First and total order Sobol's sensitivity indices of the corroded steel girder bridge at the 30-years.

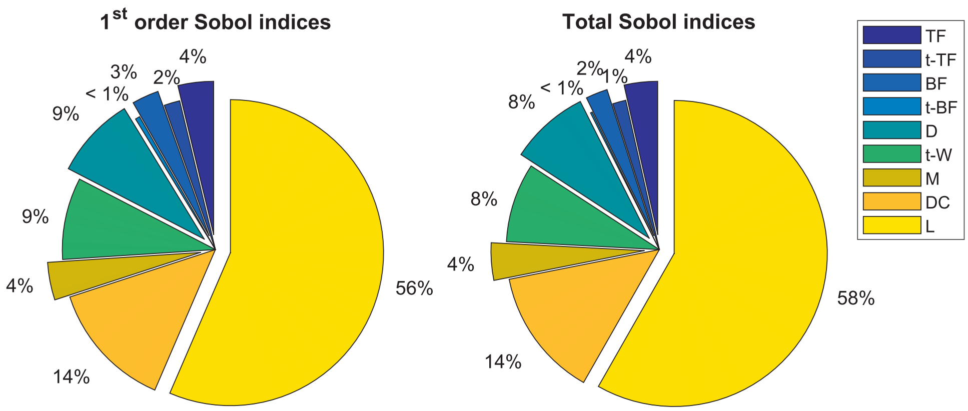


**Fig. 7.** First and total order Sobol's sensitivity indices of the corroded steel girder bridge at the 50-years.

**Table 6**
Mean estimation of first and total sensitivity Sobol's indices with 200,000 Monte-Carlo simulation.

| Variable | 1st sensitivity Sobol' indices | Total sensitivity Sobol' indices |
|---|---|---|
| $X_1$ (*TF*) | 0.0351 | 0.0269 |
| $X_2$ (*t-TF*) | 0.0126 | 0.0057 |
| $X_3$ (*BF*) | 0.0437 | 0.0356 |
| $X_4$ (*t-BF*) | 0.0043 | 0.0000 |
| $X_5$ (*D*) | 0.1052 | 0.0898 |
| $X_6$ (*t-W*) | 0.0937 | 0.0000 |
| $X_7$ (*M*) | 0.0493 | 0.0429 |
| $X_8$ (*DC*) | 0.1517 | 0.1505 |
| $X_9$ (*L*) | 0.6493 | 0.6498 |

indices has a difference. Specifically, the span of girder parameter (L) has first-order Sobol's sensitivity is 57.0% while total Sobol's sensitivity is 65%. The web thickness parameter (t-w) has first-order Sobol's sensitivity is 8.0% and total Sobol's sensitivity is close to 0.0%.

Fig. 9 shows the first (left) and total (right) order Sobol's sensitivity indices of the corroded steel girder bridge from 20th-years to 100th-years. The first-order Sobol's sensitivity value from the corrosion initiation (20th-years) has not a big difference up to the 100th-year. The parameters with specific small changes are as follows: The span of girder (*L*), web thickness (*t-w*), and top flange (*TF*) have been reduced to 1.0%. Meanwhile, the thickness of the top flange (*t-TF*) and girder height (*D*) has increased to 1.0–2.0%.

It can be seen that the first-order sensitivity indices of structural and environmental parameters on the speed limit of the car running on the corroded steel girder bridge over time have small changes. However, the first-order sensitivity indices represent the influence of each individual parameter, so it has not represented the full degree of correlation of the random parameters considering the corrosion process over time.

Fig. 9b shows the total-order Sobol's sensitivity indices of the corroded steel girder bridge from 20th-years to 100th-years. Can be seen that the total Sobol's sensitivity indices had a significant change. Specifically, the span of girder (*L*) has increased to 8.0%, the tire diameter (*DC*) and bottom flange (*BF*) have been increased to 2.0%. Meanwhile, the web thickness (*t-w*) has reduced to close to 9.0%, and the thickness of top flange (*t-TF*) has reduced to 2.0%. In addition, other parameters have negligible changes.

The total-order sensitivity indices of structural and environmental parameters for the speed limit of the car on the corroded steel bridge girders have changed significantly. This shows the interaction effect between the parameters considering the corrosion process over time. From the corrosion model and the form corrosion pattern above, can be seen that the influence of the cross-sectional of steel bridge girders parameter (*t-w*, *t-BF*, *BF*) has reduced, while the impact factor such as tire diameter (*DC*) has been increased. This result once again confirms that studying the influence of parameters considering corrosion over time helps designers and managers devise measures to maintain and improve the service life and traffic safety.

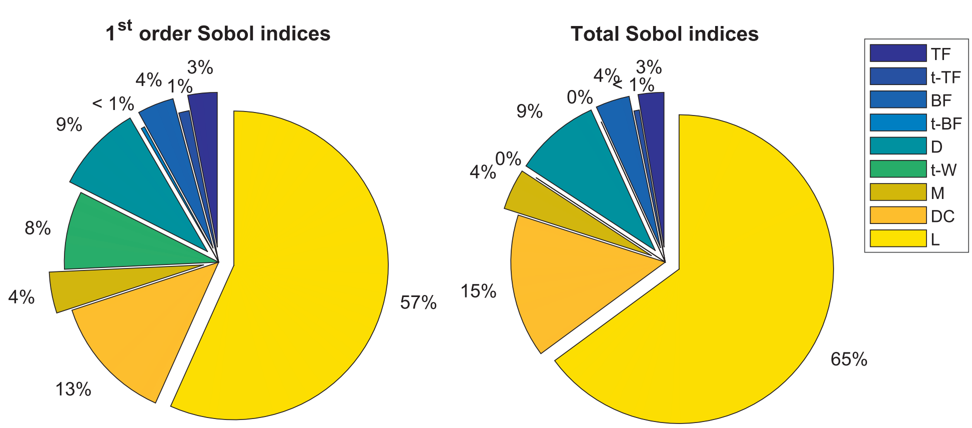


**Fig. 8.** First and total order Sobol's sensitivity indices of the corroded steel girder bridge at the 100-years.

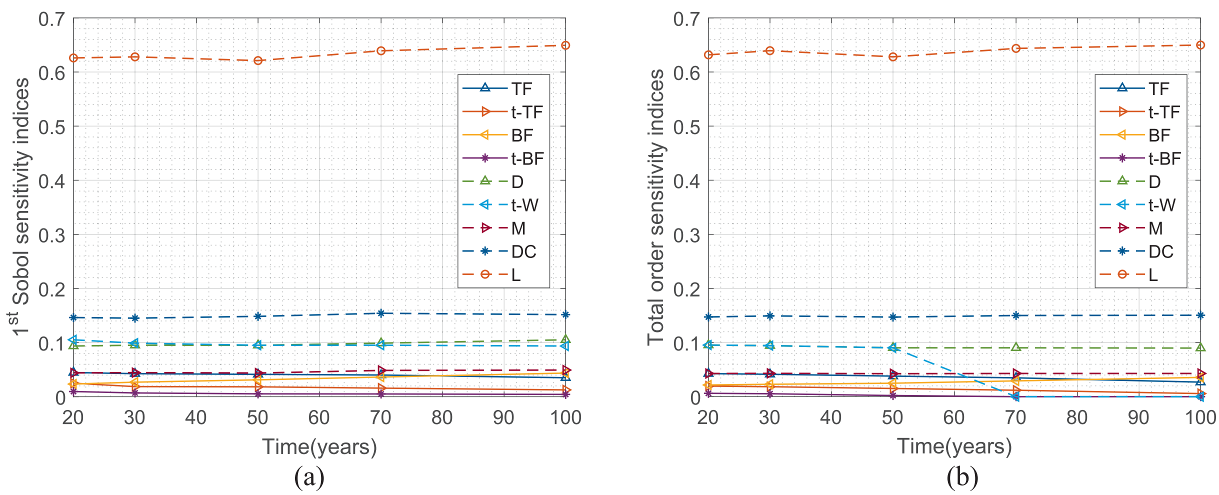


**Fig. 9.** First (left) and total (right) order Sobol's sensitivity indices of the corroded steel girder bridge from 20-years to 100-years.

## 4. Conclusions

This paper presented the effect of input structural and environmental parameters for the speed limit of the car running on the corroded steel girder bridge was using global sensitivity analysis based on Sobol's sensitivity indices by Monte Carlo simulation. Nine input parameters were investigated sensitivity value was included the car's weight (*M*) and tire diameter (*DC*), and steel girder bridge has structural parameters including top flange (*TF*), the thickness of top flange (*t-TF*), bottom flange (*BF*), bottom flange thickness (*t-BF*), girder height (*D*), web thickness (*t-w*) and the span of girder (*L*). The specific results of the study are as follows:

1) An analytical model based on resonance theory has been built to determine the speed limit;
2) The global sensitivity analysis method based on Sobol's indices was used to evaluate the effect of the parameters;
3) Effect of input parameters on the speed limit of the car running on the corroded steel girder bridge from 20th-years to 100th-years was the assessment by global sensitivity analysis based on the Sobol's sensitivity indices have been presented. The results of the sensitivity analysis show that: The first-order sensitivity indices of structural and environmental parameters on the speed limit of the car running on the corroded steel girder bridge over time have small changes. So, it has not represented the full degree of correlation of the random parameters considering the corrosion process over time. Meanwhile, the total-order sensitivity indices have changed significantly. Can be seen that the influence of the cross-sectional of steel bridge girders parameter (*t-w*, *t-BF*, *BF*) has been reduced, while the impact factor such as tire diameter (*DC*) has been increased considering corroded steel girder bridge over time.

## CRediT authorship contribution statement

**Trong-Ha Nguyen:** Writing – review & editing, Supervision. **Van-Long Phan:** Writing – review & editing. **Xuan-Hieu Nguyen:** Data curation, Visualization. **Van-Mao Nguyen:** Writing – review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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