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Cost of life extension of deteriorating structures under reliability-based maintenance

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Abstract

Due to intensive investments in the construction of civil infrastructures in the 1960s and 1970s, the number of deteriorating structures has increased considerably in the last decade. In many cases these structures require unavailable financial resources for inspection, maintenance, repair, rehabilitation, and replacement. As a consequence, there is an urgent need for developing cost-effective maintenance strategies for deteriorating structures. The existing structures management models evaluate the need for maintenance using measures of the strength deterioration of the structure. Strength deterioration is not a consistent measure of safety and for this reason, in this paper, the reliability index is used as a measure of structural performance. The time-dependent reliability index and the effect of maintenance actions are described using a model based on that proposed by the second author. In spite of the importance of the cost of a maintenance action and of its effects on the reliability index, there is very limited information on the relation between the cost and the effect of maintenance actions. In this paper, a model considering the interaction between maintenance cost and its effect on the reliability index is proposed. This model is used to compare the cost-effectiveness of several maintenance strategies for a deteriorating structure. The effect of the parameters associated with the cost model on the optimal maintenance scenario is also analyzed.

Keywords: Deteriorating structures; Cost; Maintenance; Reliability deterioration; Reliability improvement; Structural reliability; Optimum maintenance scenario

1. Introduction

Due to intensive investments in the design of civil infrastructures in the 1960s and 1970s, the number of deteriorating structures has increased considerably in the last decade. In many cases these structures require unavailable financial resources for inspection, maintenance, repair, rehabilitation, and replacement. As a consequence, there is an urgent need for developing cost-effective maintenance strategies for deteriorating structures. Making decisions on maintenance of existing structures strongly depends on the costs of interventions and the effects of these interventions on the structural safety. In this study, maintenance interventions are defined as any action whose effects are the reliability improvement, and/or the reliability deterioration delay and/or the reliability deterioration rate reduction of structural systems. Traditionally, the cost of maintenance actions is considered as fixed and independent of

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both the state of the structure and the effect of maintenance action on the structural performance. However, the cost of maintenance depends not only on the type of maintenance action, but also on the state of the structure before and after its application. As an example, the cost of repairing a corroded steel girder depends on the degree of corrosion and the extension of the repair. In this paper, a model considering the interaction between cost and its effect on the reliability index is proposed. This model is able to incorporate a wide range of maintenance actions. The time dependent reliability profile under no maintenance and the effect of maintenance actions on the reliability index are simulated using the model proposed by Frangopol [1]. The proposed cost model is used to identify the most cost-effective maintenance scenario for a deteriorating structure over a prescribed time horizon.

2. Time-dependent reliability index

The reliability index decreases over time as a result of deterioration. The reliability index is considered constant for a period of time after construction and, after this period, decreasing at a constant rate. The profile under no maintenance is defined by three variables: (a) reliability index at $t = 0$, β_0; (b) time of initiation of deterioration of the reliability index, t_i; and (c) deterioration rate of the reliability index, α. The profile under no maintenance is described as

$$\beta(t) = \beta_0 \quad \text{if } t \le t_i \tag{1}$$

$$\beta(t) = \beta_0 - \alpha(t - t_i) \quad \text{if } t > t_i \tag{2}$$

To prevent the structure from reaching unacceptable reliability levels, maintenance actions must, in general, be applied. These maintenance actions can have one, several, or all of the following effects: (a) increase in the reliability index at time of application; (b) delay of the deterioration process of the reliability index during a period of time; and (c) reduction of the deterioration rate of the reliability index during a period of time.

In this paper, as previously indicated, time-dependent reliability profiles are described based on the maintenance model proposed by Frangopol [1]. The effect of each maintenance action is modeled through several variables (see Fig. 1), such as: (a) increase in reliability index immediately after application (i.e., the difference between the reliability indices after and before application of maintenance), γ; (b) time period during which the deterioration process of reliability is delayed, t_d; (c) time period during which the deterioration rate of reliability index is delayed or reduced, t_{pd}; and (d) reliability index deterioration rate reduction, δ. The time of application of the maintenance actions is defined by two variables: time of first application, t_{pi}, and the interval between subsequent applications, t_p.

3. Cost model

Several attempts were made to analyze, predict or optimize the lifetime maintenance cost of deteriorating structural systems [2–11]. However, almost all previous attempts do not explicitly consider the relation between the total cost of maintenance interventions and its effect on the reliability index, namely reliability improvement, deterioration delay of reliability, or reduction of deterioration rate of reliability. The relation between the cost of a maintenance action and its effect on reliability index can be expressed in a general form as follows

$$C = f[\gamma; t_d; t_{pd}; \delta; \mathbf{x}] \tag{3}$$

where $\mathbf{x}$ is a vector containing cost function parameters dependent on various factors such as the type of structure and/or element and the type of maintenance action.

The relation between cost of a maintenance action and its effect on the reliability index, based on Eq. (3), can be expressed as follows

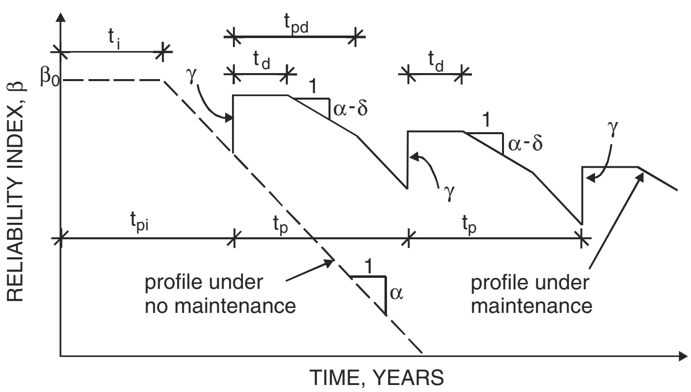


Fig. 1. Reliability index profiles under no maintenance and under maintenance and their associated variables.

$$C = C_1 + C_2\gamma^{q_1} + C_3(\gamma^*)^{q_2} \quad (4)$$

where C = total cost associated with a maintenance action, C_1 = fixed cost, C_2 = cost associated with reliability improvement, C_3 = cost associated with delay and reduction of reliability deterioration, q_1 and q_2 are parameters associated with the relation between maintenance cost and reliability improvement, and

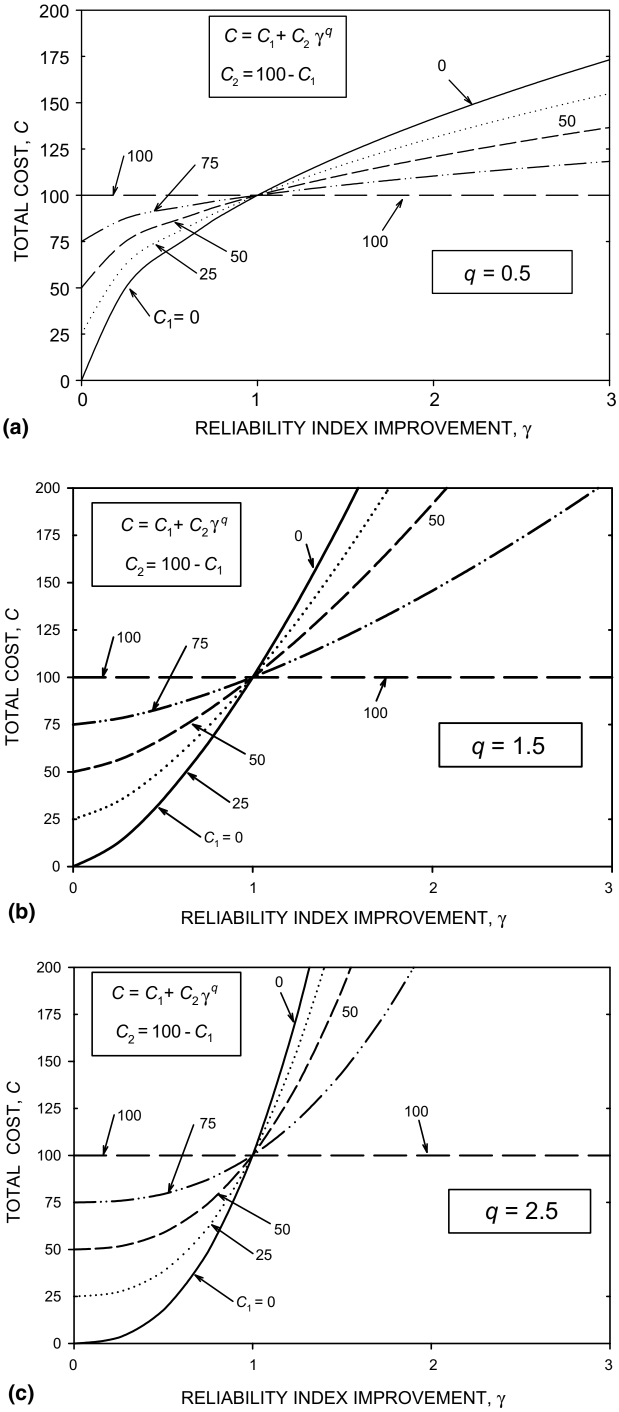


Fig. 2. Total cost of a maintenance action vs reliability index improvement for a discount rate $v = 0\%$ and (a) $q = 0.5$; (b) $q = 1.5$; and (c) $q = 2.5$.

maintenance cost and delay and reduction of reliability deterioration, respectively, and

$$\gamma^* = \alpha \cdot t_d + \delta(t_{pd} - t_d) \tag{5}$$

where γ^* is the measure of the effect on the reliability index profile of the delay in reliability deterioration rate and the reduction of the reliability deterioration rate.

Assuming maintenance actions with negligible effect on the reliability deterioration delay and on the reduction of deterioration of reliability (i.e., $t_{pd} = 0$), Eq. (4) becomes

$$C = C_1 + C_2\gamma^q \tag{6}$$

The effect of the fixed cost C_1 on the total cost C for $q = 0.5$, 1.5 and 2.5 is indicated in Figs. 2(a), (b) and (c), respectively. In these figures, it is assumed that $C_1 + C_2 = 100$ (i.e., $C = 100$ if $\gamma = 1$). As shown, for relatively small improvements in reliability (i.e., $0 < \gamma < 1$), $q = 0.5$ leads to higher total cost than that associated with $q = 1.5$ or 2.5. Conversely, $q = 2.5$ leads to higher total cost than $q = 0.5$ and 1.5 for relatively large improvements in reliability (i.e., $\gamma > 1$). This dependence between the cost of maintenance actions and the parameter q is of paramount importance in the computation of the optimal maintenance strategy, as shown in the examples presented in Section 5.

4. Discount rate

In addition to the effect of the increase in the reliability index, γ, the delay in reliability deterioration, t_d, and the reduction of the reliability deterioration rate, the effect of time of application of each maintenance intervention must also be considered when the lifetime cost of an existing structure is analyzed. In fact, the same amount of money spent at two different instants in time has different present values. As a result, costs can only be compared if converted to the same instant as follows

$$C_0 = \frac{C_t}{(1+v)^t} \tag{7}$$

where C_0 is the present value of the cost, C_t is the cost at time t and v is the discount rate. The discount rate is very difficult to predict, since it depends on the economical conditions during the life-time of the structure. In the United Kingdom, for bridge investments, $v = 6\%$ [12].

5. Applications

In order to illustrate the importance of the relation between maintenance effect on reliability and maintenance cost, several examples are herein presented.

5.1. First example

In the first example maintenance actions are considered to only lead to an increase in the reliability index at the time of application. A deteriorating structure with an initial reliability index $\beta_0 = 7$ and a reliability index deterioration rate $\alpha = 0.16$/year is considered. All the maintenance scenarios are defined considering that maintenance actions are applied when the reliability index reached the target value $\beta_{target} = 3.0$. The sum of the increases of reliability indices caused by all applications of the maintenance actions, during the prescribed time horizon of 50 years, is $\gamma_{50} = 4$. As a result,

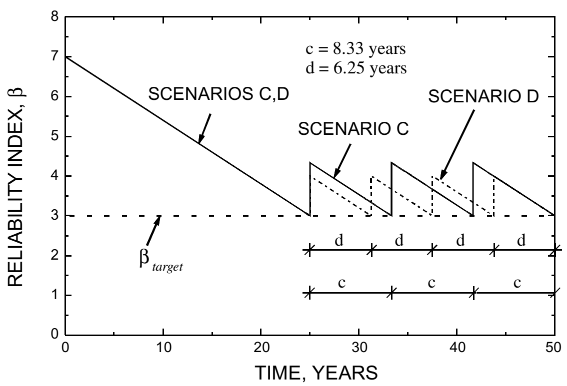


Fig. 3. Reliability profiles for maintenance scenarios C and D; lifetime improvement in reliability index due to any maintenance scenario is $\gamma_{50} = 4$.

Table 1
Descriptors of maintenance scenarios considering improvement in reliability index

Maintenance scenario	Number of maintenances n	Time of first maintenance application (years)	Interval between successive maintenances (years)	Time of last maintenance application (years)	Reliability index increase due to each maintenance γ
A	1	25.00	–	25.00	4.00
B	2	25.00	12.50	37.50	2.00
C	3	25.00	8.33	41.67	1.33
D	4	25.00	6.25	43.75	1.00
E	5	25.00	5.00	45.00	0.80
F	6	25.00	4.17	45.83	0.67

the increase in reliability index due to each nominal identical maintenance action is set as follows

$$\gamma = \frac{\gamma_{50}}{n} = \frac{4}{n} \tag{8}$$

where n is the number of applications of maintenance actions.

The increase of the reliability index, number of maintenance interventions, and the time of application of the six maintenance scenarios A, B, C, D, E, and F, considered are presented in Table 1. In Fig. 3, the reliability profiles associated with scenarios C and D defined in Table 1 are presented. In order to compare the costs

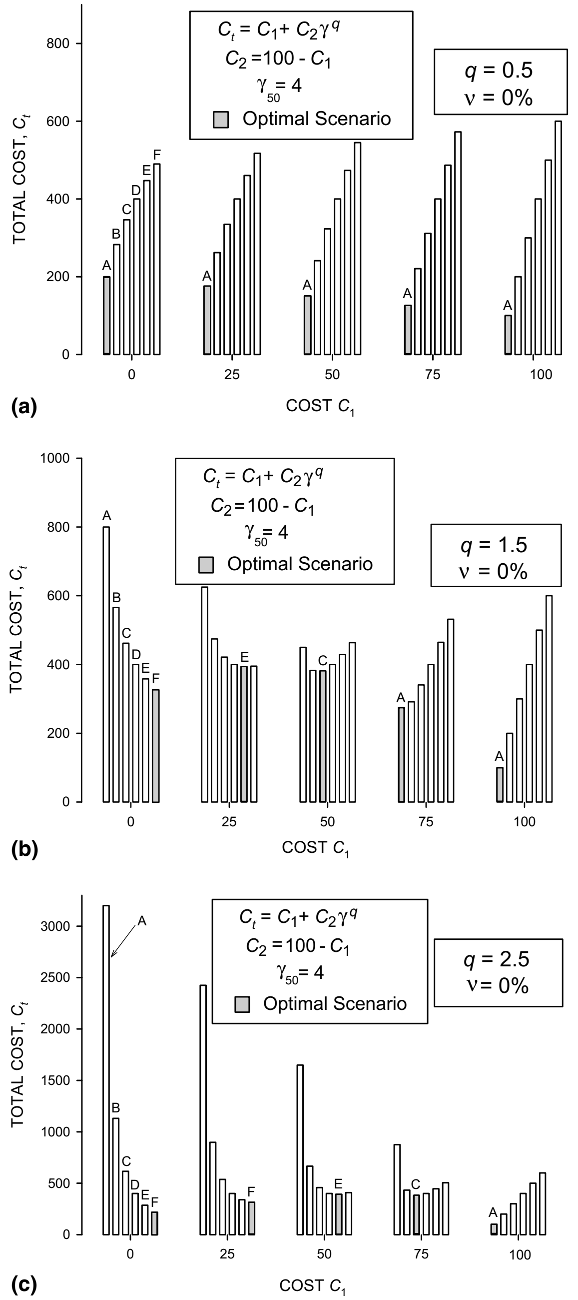


Fig. 4. Total cost of maintenance scenarios considering improvement in reliability index for a discount rate of 0% (a) $q = 0.5$; (b) $q = 1.5$; and (c) $q = 2.5$.

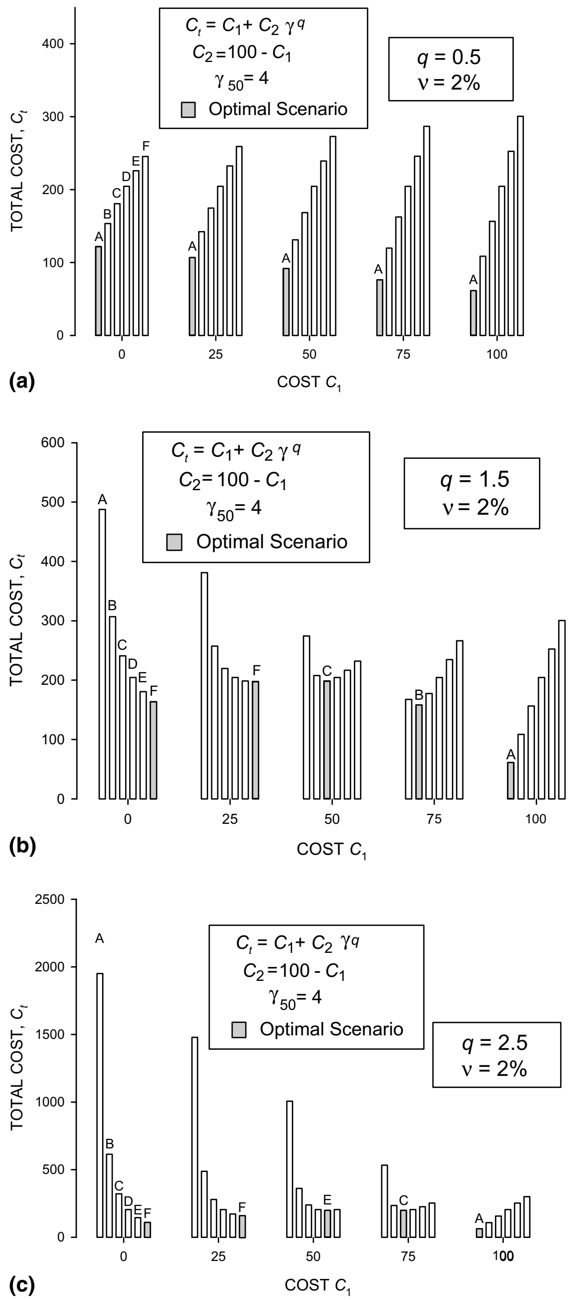


Fig. 5. Total cost of maintenance scenarios considering improvement in reliability index for a discount rate of 2% (a) $q = 0.5$; (b) $q = 1.5$; and (c) $q = 2.5$.

associated with different maintenance scenarios a calibration point ($\gamma = 1$; $C = 100$) is defined. Therefore, $C_2 = 100 - C_1$. The effect of the fixed cost C_1 on the total cost of each of the six maintenance scenarios considered is shown in Fig. 4. In this figure the optimal (i.e., minimum cost) maintenance scenarios corresponding to different values of C_1 and q are also indicated considering that costs are not discounted ($\nu = 0\%$).

From Fig. 4(a) it is clear that for a value of the parameter q lower than 1 the optimal maintenance scenario is A for all values of C_1. In Fig. 4(b) the costs of the six maintenance scenarios considering $q = 1.5$ are

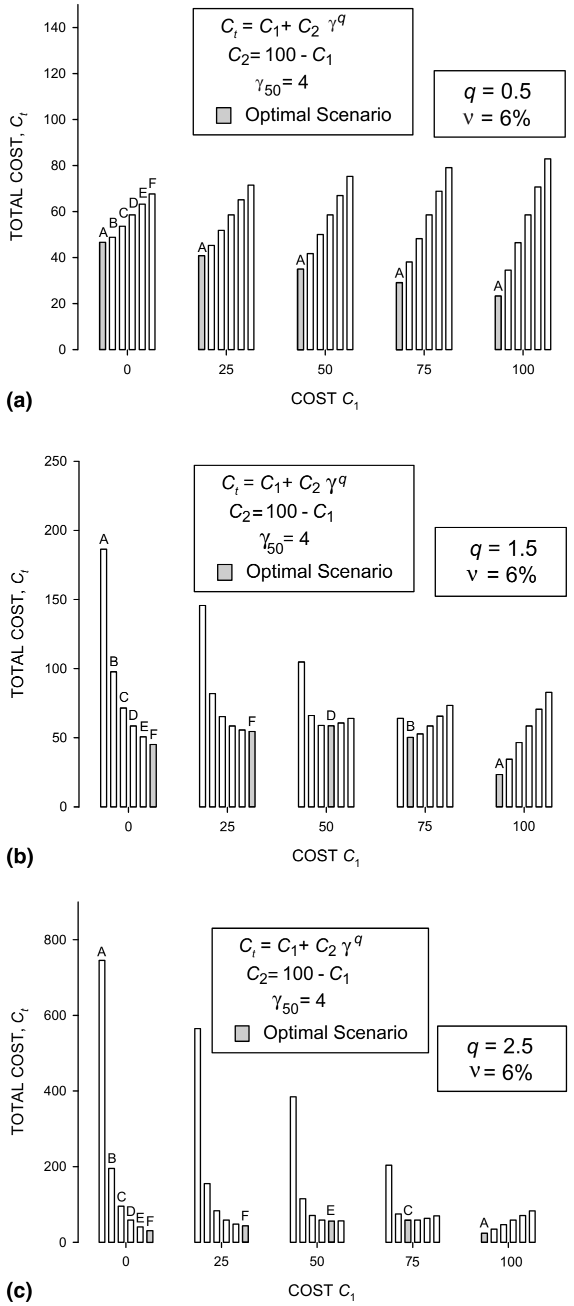


Fig. 6. Total cost of maintenance scenarios considering improvement in reliability index for a discount rate of 6% (a) $q = 0.5$; (b) $q = 1.5$; and (c) $q = 2.5$.

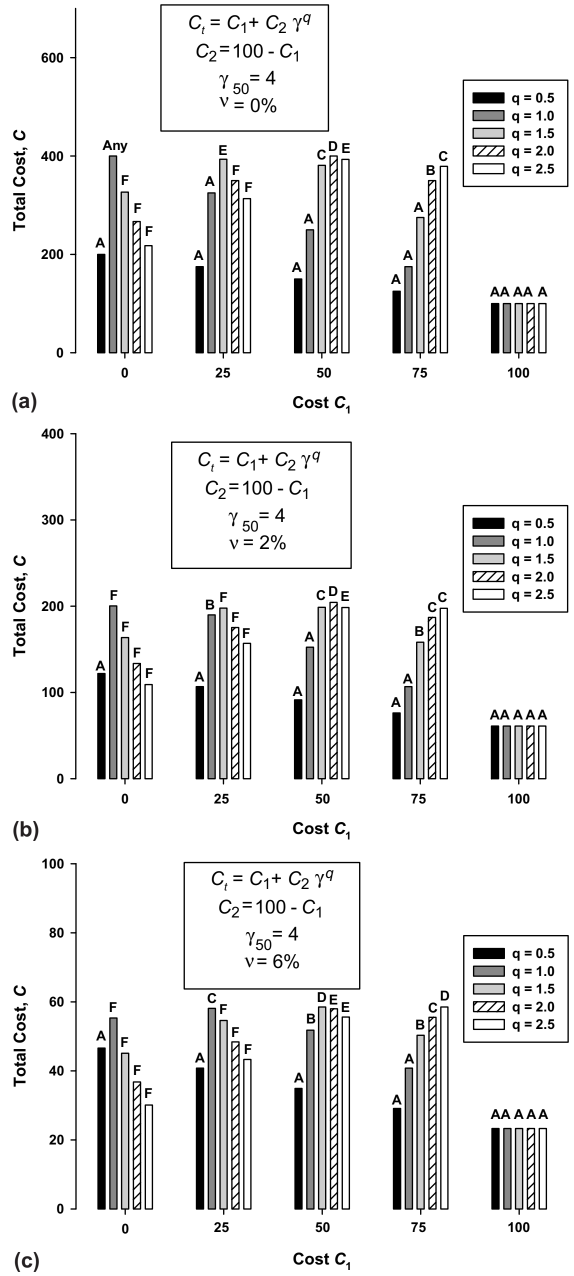


Fig. 7. Total cost of optimal maintenance scenarios considering improvement in reliability only for different values of q (i.e., 0.5; 1.0; 1.5; 2.0; 2.5) and C_1 (i.e., 0; 25; 50; 75; 100) and different discount rates: (a) $\nu = 0\%$; (b) $\nu = 2\%$; and (c) $\nu = 6\%$.

presented. In this case, the optimal maintenance scenario strongly depends on the fixed cost. If the fixed cost, C_1, is not considered, the cost of maintenance is only dependent on the effect of the maintenance action and, as a result, a scenario based on maintenance actions without significant effect on reliability improvement but applied more frequently, is the most cost-effective (i.e., scenario F). On the other hand, if the fixed cost, C_1 , is equal to 100, the cost is independent on the effect of the maintenance scenario and, as a result, the most cost-effective maintenance scenario is that associated with fewer applications (scenario A). If the parameter q is taken as 2.5 (see Fig. 4(c)) the optimal maintenance scenario is that associated with a smaller effect on reliability (i.e., scenario F) for the lowest value of the fixed cost, and with fewer applications (i.e., scenario A) for the highest value of C_1.

If costs are discounted there is a significant decrease in the lifetime cost, as shown in Figs. 5 and 6 for discount rates $v = 2\%$ and $v = 6\%$, respectively.

In Figs. 7(a), (b), and (c) and Tables 2–4 the optimal maintenance scenario for each combination of q and C_1 is presented for a discount rate of 0%, 2%, and 6%, respectively. From these figures and tables it is clear that, as q increases the optimal maintenance scenario changes from the application of maintenance actions with significant effect on reliability to actions with smaller effects applied more frequently. Conversely, as C_1 increases scenarios corresponding to a smaller number of applications become more cost effective. This tendency is unchanged by the discount rate. The optimal maintenance scenario for each combination of the fixed cost C_1 and coefficient q, for all values of the discount rate considered is presented in Table 5.

Table 2
Total cost of optimal maintenance scenarios considering $0.5 \leqslant q \leqslant 2.5$; $0 \leqslant C_1 \leqslant 100$; and $v = 0\%$

Cost C_1	q				
	0.5	1.0	1.5	2.0	2.5
0	200.0 (A)	400.0 (X)	326.6 (F)	266.7 (F)	217.7 (F)
25	175.0 (A)	325.0 (A)	393.3 (E)	350.0 (F)	313.3 (F)
50	150.0 (A)	250.0 (A)	380.9 (C)	400.0 (D)	393.1 (E)
75	125.0 (A)	175.0 (A)	275.0 (A)	350.0 (B)	379.0 (C)
100	100.0 (A)	100.0 (A)	100.0 (A)	100.0 (A)	100.0 (A)

The maintenance scenario associated with the minimum total cost is indicated in parentheses. X denotes any maintenance scenario (A, B, C, D, E or F).

Table 3
Total cost of optimal maintenance scenarios considering $0.5 \leqslant q \leqslant 2.5$; $0 \leqslant C_1 \leqslant 100$; and $v = 2\%$

Cost C_1	q				
	0.5	1.0	1.5	2.0	2.5
0	121.9 (A)	200.3 (F)	163.6 (F)	133.6 (F)	109.1 (F)
25	106.7 (A)	189.9 (B)	197.8 (F)	175.3 (F)	156.9 (F)
50	91.4 (A)	152.4 (A)	198.7 (C)	204.4 (D)	198.5 (E)
75	76.2 (A)	106.7 (A)	158.2 (B)	186.9 (C)	197.6 (C)
100	61.0 (A)	61.0 (A)	61.0 (A)	61.0 (A)	61.0 (A)

The maintenance scenario associated with the minimum total cost is indicated in parentheses.

Table 4
Total cost of optimal maintenance scenarios considering $0.5 \leqslant q \leqslant 2.5$; $0 \leqslant C_1 \leqslant 100$; and $v = 6\%$

Cost C_1	q				
	0.5	1.0	1.5	2.0	2.5
0	46.6 (A)	55.3 (F)	45.1 (F)	36.8 (F)	30.1 (F)
25	40.8 (A)	58.1 (C)	54.6 (F)	48.4 (F)	43.3 (F)
50	34.9 (A)	51.8 (B)	58.5 (D)	58.0 (E)	55.6 (E)
75	29.1 (A)	40.8 (A)	50.3 (B)	55.5 (C)	58.5 (D)
100	23.3 (A)	23.3 (A)	23.3 (A)	23.3 (A)	23.3 (A)

The maintenance scenario associated with the minimum total cost is indicated in parentheses.

Table 5
Optimal maintenance scenarios considering $0.5 \leqslant q \leqslant 2.5$; $0 \leqslant C_1 \leqslant 100$; and $0\% \leqslant v \leqslant 6\%$

Cost C_1	q				
	0.5	1.0	1.5	2.0	2.5
0	AAAA	XFFF	FFFF	FFFF	FFFF
25	AAAA	ABCC	EFFF	FFFF	FFFF
50	AAAA	AABB	CCCD	DDDE	EEEE
75	AAAA	AAAA	ABBB	BCCC	CCCD
100	AAAA	AAAA	AAAA	AAAA	AAAA

First, second, third, and fourth letter denotes the optimal maintenance scenario associated with a discount rate of 0%, 2%, 4%, and 6%, respectively.
X denotes any maintenance scenario (A, B, C, D, E, or F).

5.2. Second example

The second example analyzes maintenance actions producing both an increase in the reliability index and a delay in reliability index deterioration rate. The reliability index profile under no maintenance considered is the same as that described in the previous example. The definition of each of the five scenarios A1, B1, C1, D1, and E1, considered is presented in Table 6. The scenarios are defined so that, within the time horizon of 50 years, the reliability index would never down-cross the target value $\beta_{\text{target}} = 3.0$. For all the five scenarios a delay in reliability index deterioration of three years is assumed. In Fig. 8 the time-dependent reliability profile under maintenance scenario C1 is shown. For all scenarios in Table 6, shown in Figs. 9(a) and (b), the parameters in Eq. (4) are as follows: $C_1 = C_2 = C_3 = 50$; $q_1 = q_2 = 1.5$. The last two columns of Table 6 indicate the present value of the total cost of each maintenance scenario, considering discount rates of 0% and 6%. The discount rate plays a significant role in choosing the optimal scenario. In fact, for a discount rate of 0% the optimal scenario is B1, and for a discount rate of 6% the optimal scenario is C1.

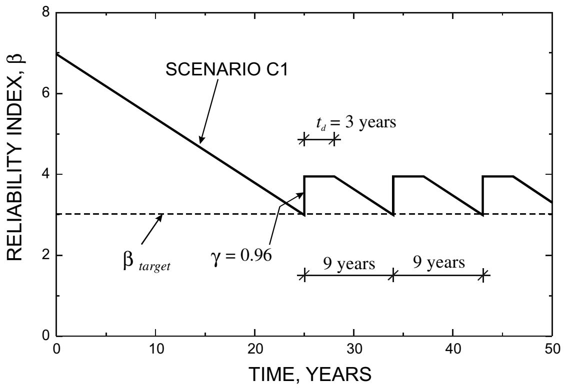


Fig. 8. Reliability profile for maintenance scenario C1; increase in reliability index $\gamma = 0.96$ and delay in deterioration $t_d = 3$ years.

In Fig. 10 the costs associated with the five maintenance scenarios considered are presented for different values of the fixed cost C_1 and for $q_1 = q_2 = 1.5$. The results show that the optimal maintenance scenario, as well as the cost of each maintenance scenario, is strongly dependent on the fixed cost. For smaller values of C_1 the optimal maintenance scenario is that corresponding to a more frequent application of maintenance actions with smaller impact on the reliability of the structure. As the fixed cost increases, the optimal maintenance scenario tends to be associated with maintenance actions with a

Table 6
Descriptors of maintenance scenarios and associated cumulative total costs considering improvement in reliability and delay in deterioration

Maintenance scenario	Time of first maintenance application (years)	Interval between successive maintenances (years)	Time of last maintenance application (years)	Reliability index increase due to each maintenance γ	Delay in reliability deterioration t_d (years)	Present value of total cost	
						$v = 0\%$ (7)	$v = 6\%$
A1	25.00	–	25	3.52	3	396.8	92.5
B1	25.00	13	38	1.60	3	**335.6**	57.4
C1	25.00	9	43	0.96	3	341.0	**51.4**
D1	25.00	7	46	0.64	3	368.9	51.6
E1	25.00	5	45	0.32	3	378.4	53.5

Note: Bold characters indicate total costs of optimal maintenance scenarios.

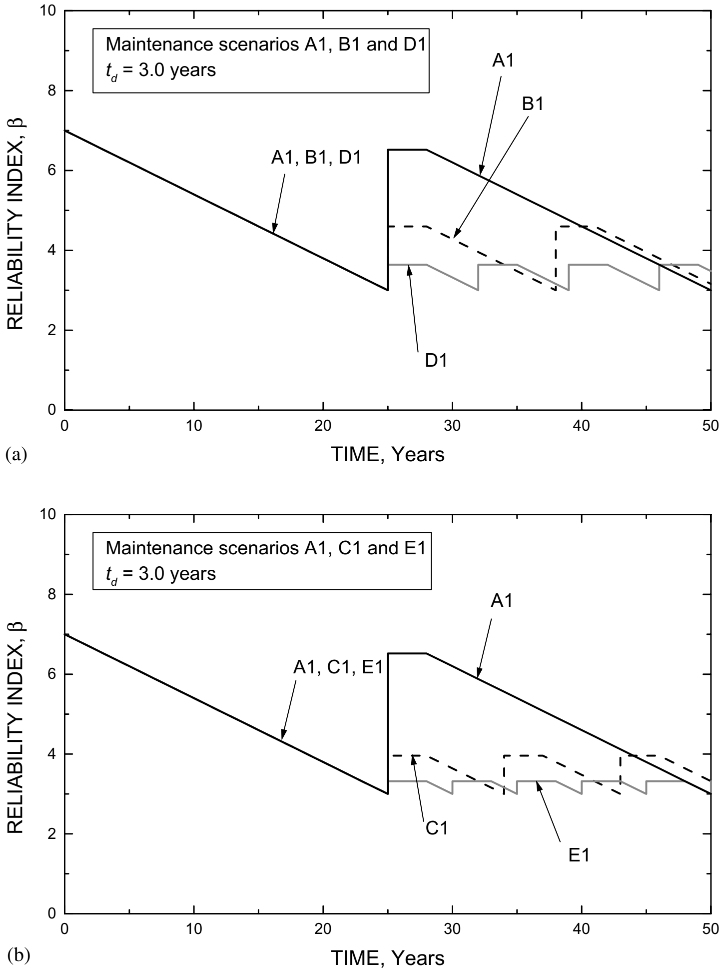


Fig. 9. Reliability profiles for maintenance scenarios (a) A1, B1, and D1; and (b) A1, C1 and E1.

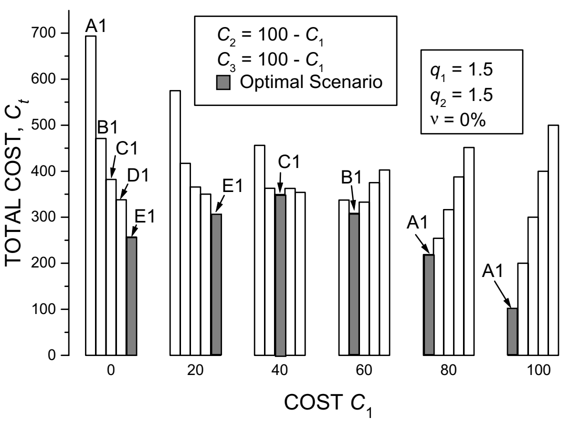


Fig. 10. Total cost of maintenance scenarios considering improvement in reliability and delay in reliability deterioration for a discount rate $v = 0\%$ and $q_1 = q_2 = 1.5$.

higher impact on the reliability of the structure but applied less frequently.

5.3. Third example

In the third example, a deteriorating structure is analyzed considering maintenance actions whose effects are similar to those of maintenance actions on existing bridges. The minimum admissible value for the reliability index is $\beta_{\text{target}} = 4.0$. The profile under no maintenance is defined by an initial reliability index $\beta_0 = 7.0$, a time of initiation of deterioration of reliability $t_i = 3$ years, and a deterioration rate of reliability index under no maintenance $\alpha = 0.16$/year.

The first maintenance scenario considered, A2, is associated with the repair and corrosion protection of most of the deteriorated components of the structure (Fig. 11(a)). This leads to a significant improvement of the reliability of the structure ($\gamma = 1.4$) and to a

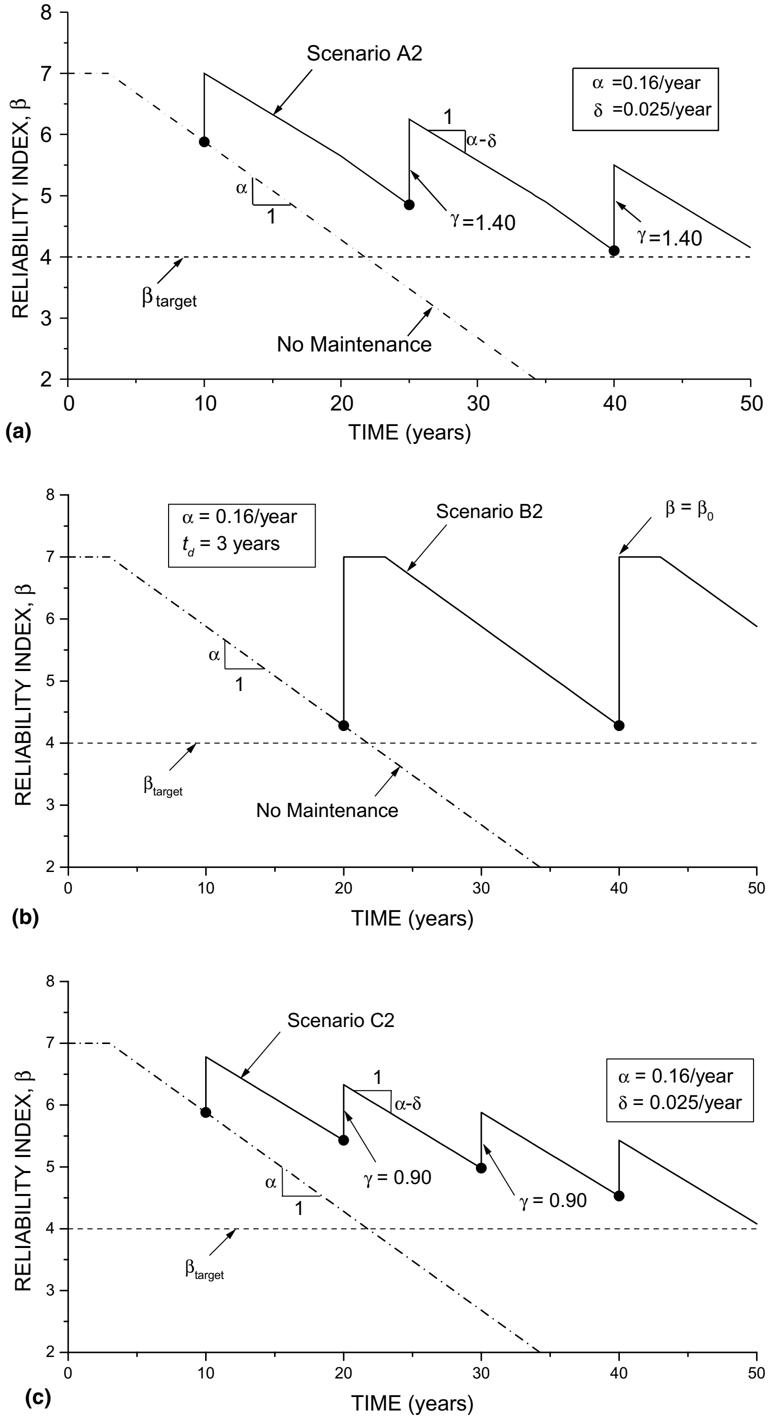
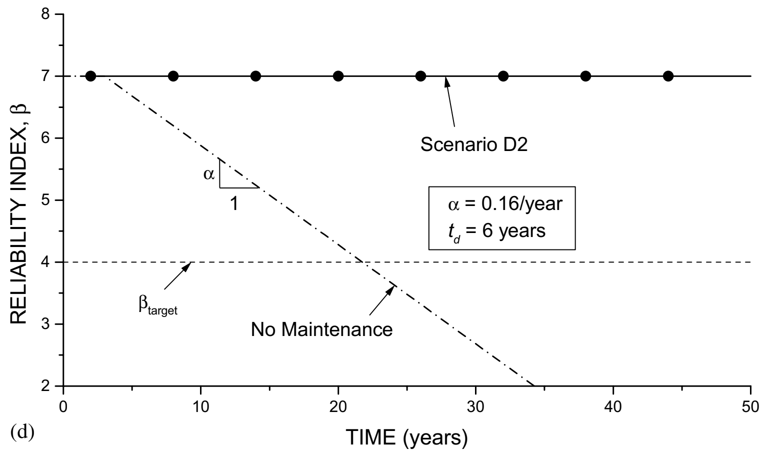
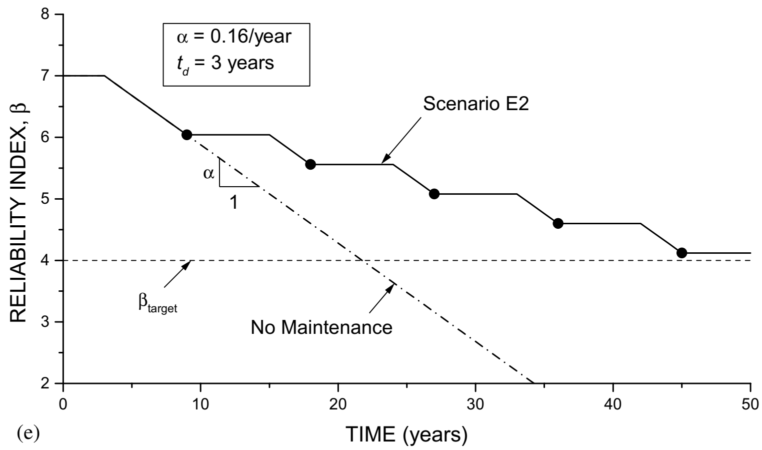


Fig. 11. Reliability profiles associated with (a) scenario A2; (b) scenario B2; (c) scenario C2; (d) scenario D2 and (e) scenario E2.

reduction of the deterioration rate of the structure ($\delta = 0.025$/year) after application of maintenance. It is assumed that the reliability index cannot increase above the initial reliability index. The second maintenance scenario, B2, models the replacement of the structure (Fig. 11(b)). This maintenance action sets the reliability index, β, to its initial value, β_0, and leads to a delay in deterioration of reliability index of three years corre-



(d)



(e)

Fig. 11 (*continued*)

Table 7
Description of maintenance scenarios, their effects on reliability, and the associated cost considering $v = 0\%$, $q_1 = q_2 = 2.5$, $C_1 = 0$ and $C_2 = C_3 = 100$.

			Effect on reliability index				
Maintenance scenario	Time of application of first maintenance t_{pi} (years)	Time of subsequent applications t_p (years)	Improvement γ	Delay in deterioration t_d (years)	Deterioration rate reduction δ (years^{-1})	Duration of maintenance effect t_{pd} (years)	Cost of application of each maintenance action considering $v = 0\%$, $q_1 = q_2 = 2.5$, $C_1 = 0$, $C_2 = C_3 = 100$
A2	10	15	1.4	0	0.025	10	135.9, 235.0, 235.0[a]
B2	20	20	[b]	3	0.000	3	1236.1
C2	10	10	0.9	0	0.025	10	80.0
D2	2	6	0.0	6	0.000	6	90.3
E2	9	9	0.0	6	0.000	6	90.3

[a] 135.9, 235.0, and 235.0 correspond to the cost of application of first, second, and third maintenance actions.
[b] Reliability index is set to its initial value.

sponding to the initiation of damage in a new structure. This is the maintenance action with the highest impact on the reliability of the structure, but also the one with a higher cost per application. The third maintenance scenario, C2, models the replacement of only a few deteriorated elements (Fig. 11(c)). It leads to a lower increase in the improvement in reliability ($\gamma = 0.9$) than that due to the maintenance action associated with scenario A2, but to the same reduction of the deterioration

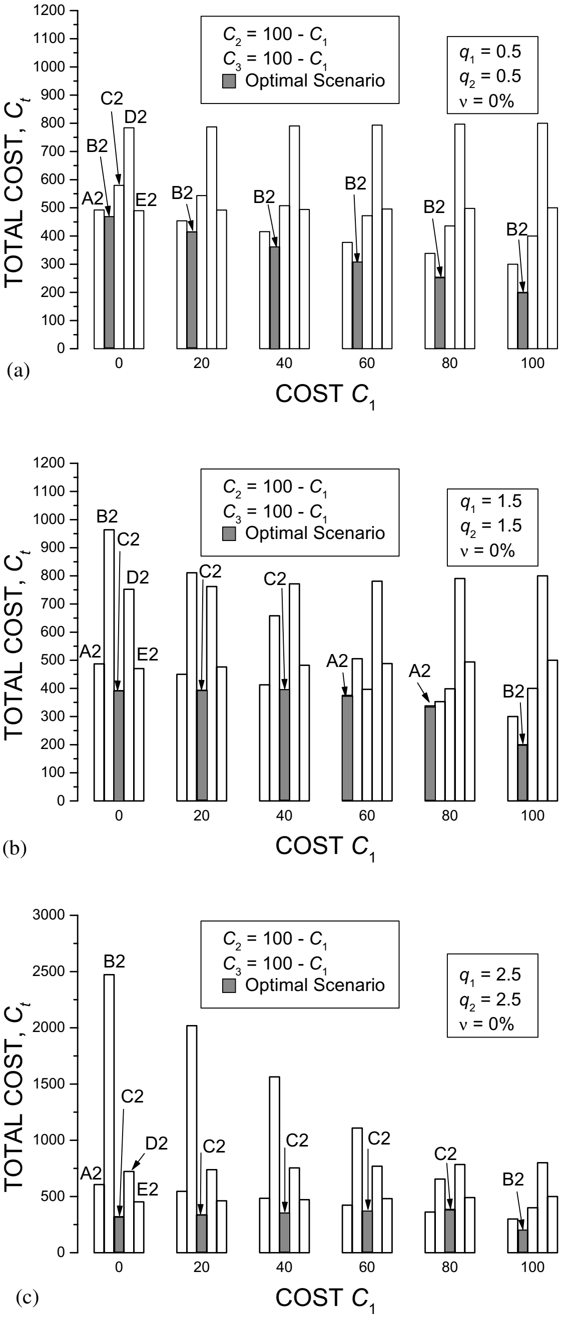


Fig. 12. Total cost of maintenance scenarios considering improvement, delay in deterioration, and reduction of deterioration rate of reliability index for a discount rate $v = 0\%$: (a) $q_1 = q_2 = 0.5$; (b) $q_1 = q_2 = 1.5$; and (c) $q_1 = q_2 = 2.5$.

rate of reliability index ($\delta = 0.025$/year). The fourth and fifth maintenance scenarios, D2 and E2, are associated with the application of coating or painting protection. The maintenance actions associated with these two scenarios produce no improvement in reliability, but only a delay in the deterioration rate of reliability index. In maintenance scenario D2 (Fig. 11(d)), actions are applied as soon as deterioration in reliability has started or the effect of the previous action has ended. This leads to an extremely safe structure during its entire lifetime but also to a higher cost than that required to keep the structure strictly above the reliability target. The maintenance scenario E2 (Fig. 11(e)) is associated with preventive maintenance actions applied at larger time intervals than those associated with D2, leading to deterioration of the reliability index.

The parameters defining the effect of each maintenance scenario on the reliability index profile as well as the time of application of each maintenance action are presented in Table 7. In column eight of Table 7 the cost of each application of the maintenance actions considering $v = 0\%$, $q_1 = q_2 = 2.5$, $C_1 = 0$, and $C_2 = C_3 = 100$ is presented. Since $C_1 = 0$ the cost of each maintenance action is solely dependent on the effect of the maintenance action on the reliability index profile. As expected, actions associated with maintenance scenario B2 (replacement of the structure) are those with a higher impact on the reliability index, followed by replacement and protection of a significant part of the deteriorated elements (maintenance scenario A2). Maintenance actions belonging to scenarios D2 and E2 have the same impact on the reliability of the structure.

In Fig. 12 the undiscounted cost of each maintenance scenario computed using Eq. (4) for different cost parameters is presented. This figure shows that for $q_1 = q_2 = 0.5$ the optimal maintenance scenario is replacement of the structure (maintenance scenario B2). When the parameters q_1 and q_2 are equal to 1.5, the optimal maintenance scenario is C2 for relatively small values of the fixed cost C_1 (i.e., $C_1 \leq 40$); however, maintenance scenarios A2 and B2 are becoming optimal as the fixed cost increases. If $q_1 = q_2 = 2.5$, the optimal maintenance scenario is replacement of some of the deteriorated elements (scenario C2) except when the cost is independent on the effect of the maintenance action on the reliability (i.e., when $C_1 = 100$).

6. Conclusions

In this paper, a model relating the cost of maintenance actions to its effects on the reliability index profile is presented. The reliability profile is defined using the model proposed by Frangopol [1] and the effect of maintenance on reliability is defined by the improvement of the reliability index, the delay of reliability index deterioration, and the reduction of the deterioration rate of the reliability index. The main advantage of the proposed cost model is the flexibility and expandability obtained from using the same expression for several maintenance actions. The results presented show that the relation between reliability and cost can significantly affect the optimal maintenance scenario. The proposed cost model can be used in structure maintenance systems, as it provides a powerful tool for taking into account the interaction between the effects of maintenance actions on structural reliability and the costs of maintenance actions. Further research is needed to adequately quantify the parameters used in Eq. (4) for different structures. Steps in this direction are already in progress [13].

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