Electronic Supplementary Materials

For https://doi.org/10.1631/jzus.A2400484

Reliability-based optimization of laterally loaded piles with necking defects

Yang YU[1,2], Bo SHI[1], Qing LÜ[3], Chaofeng WU[1,4]

[1]*Ocean College, Zhejiang University, Zhoushan 316021, China*
[2]*Hainan Institute of Zhejiang University, Sanya 572025, China*
[3]*College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, China*
[4]*China Energy Engineering Group Zhejiang Electric Power Design Institute Co., Ltd., Hangzhou 310012, China*

Table S1

In Table S1, it can be observed that as the cost increases, the design robustness (as indicated by the standard deviation of deflection) also increases. This suggests that a more robust design can be achieved by investing more resources. As a result, it impossible to find a design with the lowest possible cost and best possible design robustness. In the principle of RGD, the optimal design is one that balances cost and design robustness, which is defined as the knee point of the Pareto front.

Table S1 Design parameters of feasible designs on the Pareto front

NO.	Design parameters (L, D)	Cost	Standard deviation of deflection (mm)	Euclidean distance
1	(24.0 m, 1.0 m)	18.840	0.295	1
2	(26.0 m, 1.0 m)	20.410	0.212	0.685
3	**(20.0 m, 1.2 m)**[a]	**22.608**[a]	**0.137**[a]	**0.437**[a]
4	(34.0 m, 1.0 m)	26.690	0.101	0.474
5	(28.0 m, 1.2 m)	31.651	0.091	0.688
6	(34.0 m, 1.2 m)	38.434	0.035	1

[a] The **bold** row represents the design at the knee point

Section S1

The function "ksecd" is used in column "ksecd" of Figure 2, and reads its parameter y from column "yprev". Eqs. (10), (11) and (12) that describe the p-y curve are incorporated in this function. Details of the function are as follows.

```
Function ksecd (C1, C2, C3, d, gamma, z, k, y)
If z < 10 ^ (-6) Then z = 10 ^ (-6)
pu = (C1 * z + C2 * d) * gamma * z
If pu > C3 * d * gamma * z Then pu = C3 * d * gamma * z
a = (3 - 0.8 * z / d)
If a < 0.9 Then a = 0.9
y = Abs(y)
If y < 10 ^ (-6) Then y = 10 ^ (-6)
Tanh = Application.WorksheetFunction.Tanh(k * 2.5 * (z / 2.5) ^ 0.6 * (0.61 / d) ^ 0.5 * y / (a * pu))
p = a * pu * Tanh
ksecd = p / y
End Function
```

Section S2

The function "Sub Iterate_ksecd", is proposed in the research of Low et al. (2001), is used to iteratively updated the secant modulus of the p-y curves presented in Section 2.2. Details of the function are as follows.

```
Sub Iterate_ksecd ()
Application.ScreenUpdating = False
del = 0.000001 'convergence criterion
For i = 1 To 200
  'Ranges "yprev" & "yi" are predefined column names.
  If i = 1 Then Range("yprev").Value = 0.0001
  If i > 1 Then Range("yprev").Value = Range("yi").Value
  SolverSolve True
  If Range("maxdiff") < del Then Exit For
Next i
Application.ScreenUpdating = True
End Sub
```

Section S3

The methodology proposed by Khoshnevisan et al. (2014) is employed to establish the Pareto front and identify the knee point. In order to establish the Pareto front, three steps must be completed. In the initial phase, the cost of the least expensive design and the cost of the most robust design are identified among all feasible designs. In the second step, the cost interval [C_L, C_R] is divided into several cost levels, which are denoted as $C_T = \{C_1, C_2, C_3, \ldots\ldots, C_n\}$. In the third step, the optimal robust design is identified within each cost level. These optimal robust designs collectively constitute the Pareto front.

The method for obtaining the Knee point can be determined by the minimum distance method, and the steps are as follows:

Step 1: Normalize Cost and robustness indexes, as shown in Eq. (S1):

$$X_n = \frac{X_j - X_{j,\min}}{X_{j,\max} - X_{j,\min}} \quad \text{(S1)}$$

where $X_{j,\min}$ is the minimum value of the jth robustness indicator, $X_{j,\max}$ is the maximum value of the jth robustness indicator, and X_n is the normalized value of the jth robustness indicator. After normalization, the coordinate of utopia point is (0,0), that is, Cost is the lowest and robustness is the best.

Step 2: According to Eq. (S2), the Euler distance of each design combination on the Pareto front can be obtained:

$$L_e^n = \sqrt{\left(x_1^n - 0\right)^2 + \left(x_2^n - 0\right)^2} \quad \text{(S2)}$$

where L_e^n is the distance between the nth feasible design combination and the utopian point, x_1^n is the Cost corresponding to the nth feasible design combination, and x_2^n is the robustness index corresponding to the nth feasible design combination.

For detailed steps of establishing Pareto frontiers and gateways, please refer to Deb and Gupta (2011). According to the above steps, the optimal design can be obtained. This optimization design method takes into account the influences induced by the necking defects and the cost.