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Reliability Analysis of Anchored Geotechnical Structures for the Design Limit States

Sohaib Kareem Al-Mamoori [1*] | Laheab A. Al-Maliki[2] | Khaled El-Tawel[3]

Affiliations
[1]Department of Environmental Planning, Faculty of Physical Planning, University of Kufa, Najaf, Iraq.

[2]Department of Hydraulic Engineering Structures, Faculty of Water Resources Engineering, University of Al-Qasim Green, Babylon, Iraq.

[3]Faculty of Engineering, Lebanese University, Beirut, Lebanon

Correspondence
Sohaib Kareem Al-Mamoori,
Email:
sohaib.almamoori@uokufa.edu.iq

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Abstract
Reliability has been considered of magnificent importance in engineering design specially in geotechnical engineering due to the unpredictable conditions of soil layers. It is essential to establish well-designed failure modes that could guarantee safety and durability of the proposed structure. This study aims to suggest a reliability analyses procedure for retaining walls by the mean of a reliability index β using the specifications of AASHTO Bridge Design 2002, Eurocode 7, and DIN EN 1993-5 norms. Two failure modes; Tensile failure of tendon (G1) and Failure by bending (G2) were studied and compared by using equation of the Design Limit State (DLS) and by taking some basic geotechnical parameters as Random Variables RV. The analyses demonstrated that the reliability index β and probability of failure P_f are the most important parameter in the reliability analysis. Also, the suitable height (H) for the retaining structure (for all angles ϴ) equals to 6 m and the most critical angle is ϴ= 45º to prevent the failure by tensile of tendon. While the bending failure reliability analysis shows that all heights of retaining structure are suitable. After comparing the two cases it was found that (G1) is more dangerous than (G2).

Keywords: Anchor Retaining Structure, geotechnical limit states, reliability analysis, Hasofer-Lind index, Tensile failure of tendon, Failure by bending

الخلاصة: تعتبر الموثوقية ذات أهمية كبيرة في التصميم الهندسي خاصة في الهندسة الجيوتقنية بسبب الظروف غير المتوقعة لطبقات التربة. من الضروري التنبئ بأوضاع فشل المتوقعة عند تصميم الجدران الساندة حتى تكون اكثر سلامة ومتانة هيكل المقترح اثناء التصميم. تهدف هذه الدراسة إلى اقتراح إجراء تحليل موثوقية للجدران الاستنادية عن طريق مؤشر الموثوقية (β) باستخدام مواصفات معايير AASHTO Bridge Design 2002 و Eurocode 7 و DIN EN 1993-5. تمت دراسة وضعيتان للفشل هما فشل الشد للوتر (G1) والفشل عن طريق الانحناء (G2) باستخدام معادلة حالة حدود التصميم (DLS) وباستخدام الخواص الجيوتقنية الأساسية كمتغيرات عشوائية (RV). أظهرت التحليلات أن مؤشر الموثوقية (β) واحتمال الفشل (Pf) هما أهم عامل في تحليل الموثوقية, لتحديد الحالة الاخطر عند التصميم. وأيضًا ، الارتفاع المناسب (H) للهيكل المحتجز (لجميع الزوايا ø) يساوي ٦ أمتار والزاوية الأكثر أهمية هي ø = 45º لمنع فشل شد الوتر. بينما يوضح تحليل الموثوقية لنمط الفشل G2 أن جميع ارتفاعات الجدران الساندة مناسبة لها. وبعد المقارنة بين الحالتين تبين أن (G1) أخطر من (G2).

1. INTRODUCTION

It is known that the factors of safety in geotechnical engineering design have a major effect more than those in any other structural engineering design [1]. This is because the soil has an unpredictable character in addition to the errors that occurred in soil tests, whether in situ or in laboratories [2-4]. Traditional, designing of retaining structures has been carried out according to either the Rankine or Coulomb earth pressure theory [5]. The safety factor FS is used for the design to deal with the uncertainty in the design. FS is assumed based on engineering experience and judgment. However, a higher FS should be used when the uncertainties are high [6]. The benefit of the reliability approach is that a direct relationship can be determined between uncertain variables and the probability of failure in any mode, and this is what "the reliability analysis" means. So, it is important to reevaluate the limit states on a reliability base to show the level of security. To do that, considering the efficacious parameters in each limit state as random variables are required based on previous studies and experiences [7-9]. Many studies have been conducted; Christian et al. (1994) [10], Chowdhury and Xu (1995) [11], Tang et al. (1976) [12] and others have described excellent examples of the use of reliability analysis in geotechnical engineering [13]. Duncan (2000) suggested that the safety factor is not adequate alone for risk evaluation, and it should be used in conjunction with reliability indexes [14]. Kok-Kwang Phoon has performed many studies regarding reliability in geotechnical engineering [15-21].

This study provides a description of a reliability analysis procedure to evaluate the degree of reliability of the existing geotechnical design of anchored and cantilevered flexible retaining structures, as expressed by the reliability index β using the specifications of AASHTO Bridge Design 2002, Eurocode 7, and DIN EN 1993-5 norms.

2. MATERIALS

2.1. Limit State Functions

The Load and Resistance Factor Design (LRFD) is used in a large format to include procedures which seek all limit states need to be checked using a particular design including load and resistance factors. The basic format of the limit state equation Gi is expressed as the difference between two major quantities [22-24]:

$$Gi=R-S \leq 0 \quad (1)$$

Where R is the resistance force, and S is the load effect. Anyway, R and S are produced in terms of parameters such as loads and soil properties. In reliability indices, analysis and computation, all wall components (for example, embedded depth D and length of anchor Lb) were dimensioned relatively to a particular load and resistance factors, γ and Ø, respectively [25]. Besides, R and S values assimilated the nominal resistance and load and were based upon elements dimensions, which were sized relatively to γ and Ø values.

Passive Resistance (Embedment)

For passive resistance of a separate anchored vertical wall, function of the limit state (G2) can be given in terms of resisting force and the applied force (load) as [26]:

$$G2= Hp - Ha \quad (2)$$

Where: HP = passive pressure resisting force

Ha = active earth pressure component applied at the exposed base of the wall. See Fig. 1.

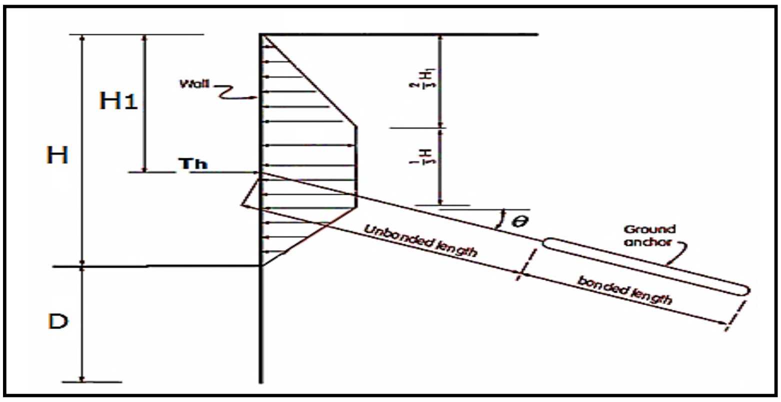


Figure 1 The Main Component of the Anchored Retaining Structure [27].

In cohesionless soil retained by one level anchored walls, the active earth pressure component applied at the wall base Ha is [28, 29]:

$$H_a = \frac{13(H-2H_1)h}{54(H-H_1)} K_a \gamma H S_h \quad (3)$$

Where:

Ha: Active earth pressure component applied at the exposed base of the wall

H: The exposed retaining structure height (m)
H_1: The distance between the ground surface and anchor head (m)
Ka: Coefficient of active lateral earth pressure = **[(1-sin Ø) \ (1+ sin Ø)]**
γ: Unit weight of soil (KN\m^2)
S_h: Horizontal anchor spacing (m)

2.2. Selection of Random Variables (RV.)

The quality of the system calculation or design is affected directly by the selected random variable [30]. This system has many parameters including soil parameters such as (γ) unit weight, (Ø) friction angle, (τ_{ult}) ultimate anchor bond stress, (H, H1, D) dimensions and (q_s) live load above the ground surface [32]. Also, Physical and indicator of cohesionless soil as well as the interaction between the wall and anchor rod. The amount of calculation may be very large if all parameters counted as random variables. Besides, it is impossible to consider all of the parameters as random variables because of limited statistical analysis information presently. So, when analyse retaining structure system reliability, take those that have mainly affect the system reliability as random variables and take another as a certain value [1, 32]. Experimental geotechnical designs have been carried out for anchored and cantilevered retaining elements. To facilitate computations, it was assumed that the spacing between separated vertical embedded anchor walls elements works independently (viz interaction leverage were neglected). As well, cantilever retaining elements were presumed to have a continuous wall [33]. The procedure of reliability analyses was conducted for separate anchor wall elements entrenched in cohesionless soils which retain cohesionless and stiff cohesive soil. Only cohesionless soil has been taken into consideration as long as the design of continuous cantilever walls is involved [25 and 26]. For this study, the inputs for the limit states at θ=0 will be entered in the program with five different heights of retaining structures (H=4.5, 6, 8, 10 and 11.5 m), and recalculated for the angles 15°, 30°, 35°and 45°. The random variables are listed in tables 1 and 2.

Table 1 Random variables for G1

	Parameters	Mean Value	SD	COV	LAW
1	$\gamma\ (KN/m^3)$	17	0.85	0.05	Normal
2	Ø	38	2	0.05	Normal
3	H (m)	4.5	0.5625	0.125	Normal
		6	0.75		
		8	1		
		10	1.25		
		11.5	1.4375		
4	$f_t\ (KN/mm^2)$	0.55	0.055	0.1	Normal
5	$q_s\ (KN/m^2)$	10	2	0. 2	Normal
6	$H_1(m)$	1.5	0.075	0.05	Normal

Table 1 Random variables for G2

	Parameters	Mean Value	SD	COV	LAW
1	$\gamma\ (KN/m^3)$	17	0.85	0.05	Normal
2	Ø	38	2	0.05	Normal
3	H (m)	4.5	0.5625	0.125	Normal
		6	0.75		
		8	1		
		6	1.25		
		11.5	1.4375		
4	$H_1(m)$	1.5	0.075	0.05	Normal
5	$q_s\ (KN/m^2)$	10	2	0. 2	Normal
6	F_y	1590	15900	0.1	Normal
7	R	0.1	0.01	0.1	Normal

3. METHOD

3.1. Reliability Analysis Procedure

Depending on the function ($= R - S$) value, structures can be divided into three states:

- **i.** Reliable state, when $= R - S > 0$.
- **ii.** Limit state, when $= R - S = 0$.
- **iii.** Failure state, when $= R - S < 0$.

Usually, the basic variable, X_i, that used to describe structure is random. Therefore the structure reliability can be defined with probability when the structure is in a reliable, which described by P_S :

$$P_S = P(\quad > 0) \tag{4}$$

It presumed that R is the random variable for resistance force, and S is the random variable for the effective load. $f_S(S)$ and $f_R(r)$ are probability density functions for S and R respect $F_R(r)$ and $F_S(s)$ are probability distribution functions accordingly. R And S are independent [15].

$$P_f = P(\quad > 0) = \int_0^{\infty} f_s(s) \left[\int_0^{\infty} f_R(R)\, d_R \right] d_S \tag{5}$$

The structure reliability can also be measured with probability failure P_f, which is the probability that the structure cannot implement its function.

$$P_f = P(\quad < 0) = \iint_{r<\ <}^{\cdot} f_R(r) f_S(s)\, ds\, dr$$

$$P_f = \int_0^{\infty} \left[\int_0^{s} f_R(r) dr \right] f_s(s) ds = \int_0^{\infty} F_R(s) f_s(s) ds \tag{6}$$

Or

$$P_f = P(\quad < 0) = \int_0^{\infty} \left[\int_0^{\infty} f_s(s)\, d_s \right] f_R(r)\, d_r$$

$$P_f = \int_0^{\infty} [1 - F_S(r)] f_R(r) dr \tag{7}$$

The reliability and failure for a structure are not compatible cases, that is P_s and P_f are complementary, therefore, $P_s + P_f = 1$. The relationship between Reliability Index β and Probability of Failure (P_f) is :

$$P_f = \Phi(-\beta) \tag{8}$$

In this study, the margin of safety values (G) were Obtained by utilising the (Hasofer-Lind Method). Plot the resulting cumulative distribution function of G on a normal scale of probability to determine β, and P_f relationship is shown in Table 3.

Table 2 Reliability Index β and Probability of Failure P_f relationship

Reliability Index β	Probability of Failure (P_f)
0	0.5
0.5	0.309
1	0.159
2	0.0228
3	1.35×10^{-3}
4	3.17×10^{-5}
4.5	3.4×10^{-6}
5	2.87×10^{-7}
5.5	1.9×10^{-8}
6	9.87×10^{-10}

As the reliability index β is a guide to the safety engineering design when they are worth between 2.5 to 3.5, And when the β is more than that the safety factor, the design is not economic, but if the β less than that, the safety factor is not enough and have very high risk [34].

3.2. Reliability Application on The Limit State

This application considers two failure modes, namely tensile failure of tendon and failure by bending, these two modes are investigating Anchored and Cantilevered Flexible Retaining elements which are both essential to being considered in terms of design. Accordingly, in geotechnical engineering and the reliability analysis, two major determinants were emphasised which are the reliability index β and the probability of failure (P_f), in addition, two programs were utilised in the reliability analysis which was lifeRel & comRel. The input data in this program are the limit state equation and the random variables. The general limit state equation is [35]:

$$Gi=R\ (\text{total resistance force})-S\ (\text{total applied force}) \leq 0 \tag{9}$$

The random variables in the first mode are (Ø, γ, H, H1, qs and τ_{ult}) and the random variables in the second mode are (Ø, γ, H, H1, d, and q_s).

Let us consider equation (9): five different heights of retaining structures were used (4.5, 6, 8, 10 and 11.5 m), for each one of these heights, five different angles θ° (0°, 15°, 30°, 35°and 45°) were used. The output results from the program are the Hasofer-Lind reliability index β, the probability of failure (P_f) (FORM) and the Importance Random Variables percentage (IRV %). From β and (P_f) it can be deduced the appropriate, the critical, and the overvalue of height for these failure modes.

4. RESULTS AND DISCUSSION

4.1. Tensile Failure of Tendon G1

In this application, we will consider the failure mode named "Tensile failure of the tendon" that investigate the failure by the tension of the free section of the anchor rod. Where R is the total resistance force, and E is the total applied force (live load and dead load). The limit state equation is:

$$G\_1=R-E \leq 0 \tag{10}$$

The input data in this program are the limit state and the random variables; the random variables are (ft, Ø, γ, H, H1 and qs). Let us consider equation (10):

Five different heights were used for the retaining structure (H= 4.5, 6, 8, 10 and 11.5) m, for each height, five different angles (θ =0°, 15°, 30°, 35°and 45°). The output results from the program are the reliability index β, the probability of failure P_f and the importance value. From β and P_f we can deduce the appropriate, the critical and the over height for the retaining structure in this mode failure,

- ❖ The total applied force (live load and dead load) E is:

$$E = \left[S_h \left(DL.\gamma_G + LL.\gamma_Q\right)\right] \tag{11}$$

$$DL = \frac{T_h}{\cos\theta} \tag{12}$$

$$T_h = P\left(\frac{23H^2 - 10HH_1}{54(H - H_1)}\right) \tag{13}$$

$$P = K_a\gamma H - 2c\sqrt{K_a} \qquad \text{for sand soil } c = 0 \tag{14}$$

$$DL = \frac{K_a\gamma H}{\cos\theta}\left[\frac{23H^2 - 10HH_1}{54(H - H_1)}\right] \tag{15}$$

$$LL = qs \times K_a\left(\frac{H + H_1}{2}\right) \tag{16}$$

$$(E) = S_h K_a\left[\frac{\gamma \times H \times \gamma_G}{\cos\theta}\left[\frac{(23H^2 - 10HH_1)}{54(H - H_1)}\right] + \frac{\gamma_Q \times q_s}{2}(H + H_1)\right] \tag{17}$$

- ❖ The total resistance force R:

$$R = \left(A_s\,\frac{f_t}{\gamma_M}\right) \tag{18}$$

- The limit state equation will be:

$$_1 = \left[A_s \frac{f_t}{\gamma_M}\right] - S_h K_a \left[\frac{\gamma \times \gamma_G}{\cos\theta}\left(\frac{23H^3 - 15H^2}{54(H - H_1)}\right) + \frac{\gamma_Q \times q_s}{2}(H + H_1)\right] \le 0 \qquad (19)$$

The results are shown in Table 4.

Table 3 Reliability index ($\boldsymbol{\beta}$) and probability of failure for G1

H		θ°	β	P_f
1	4.5 m	0	5.59	1.13e-08
		15	5.46	2.367e-08
		30	4.95	3.595e-07
		35	4.828	6.828e-07
		45	4.24	1.1e-05
2	6 m	0	3.437	2.936e-04
		15	3.299	4.844e-04
		30	2.77	2.73e-03
		35	2.64	4.04e-03
		45	2.069	1.925e-02
3	8 m	0	1.27	0.1017
		15	1.14	0.1268
		30	0.658	0.2553
		35	0.54	0.295
		45	0.0134	0.4946
4	10 m	0	-0.284	0.612
		15	-0.402	0.656
		30	-0.837	0.798
		35	-0.944	0.827
		45	-1.410	0.920
5	11.5 m	0	-1.177	0.88
		15	-1.285	0.9
		30	-1.686	0.954
		35	-1.783	0.963
		45	-2.208	0.986

It can be deduced from Figures (2- 4) that the suitable (H) for the retaining structure (for all angles θ°); is 6 m which is suitable for design work to prevent the failure by tensile of the tendon. But when H < 6 m gives an over safety, while H > 6 m gives a critical safety. Also, the suitable $\Theta = 0$ and the most critical angle is $\Theta = 45^{\circ}$

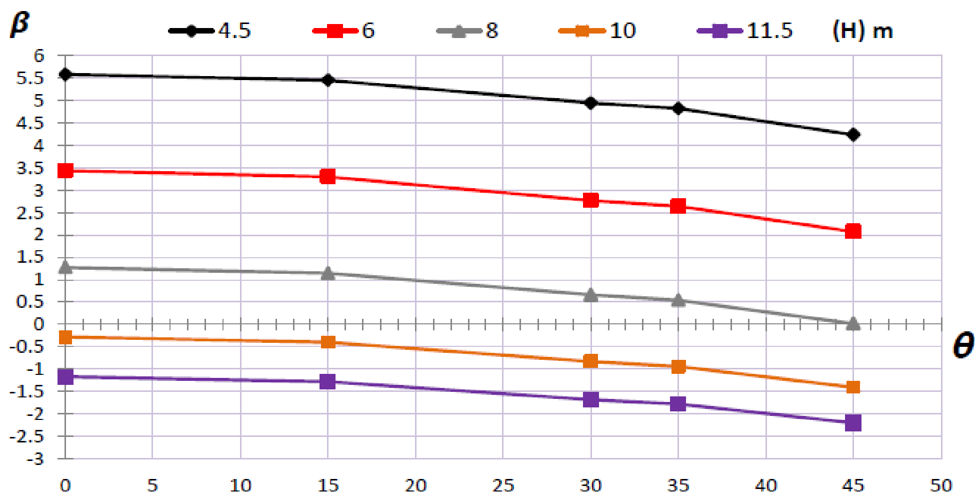


Figure 1 The reliability index with anchor inclination of angle for G1

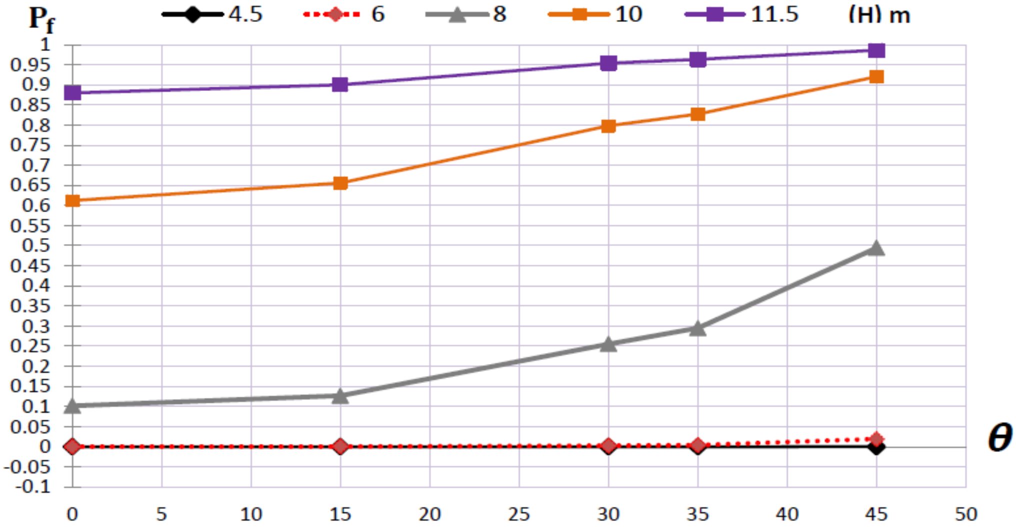


Figure 2 Probability of Failure with Anchor Inclination of Angle for G1

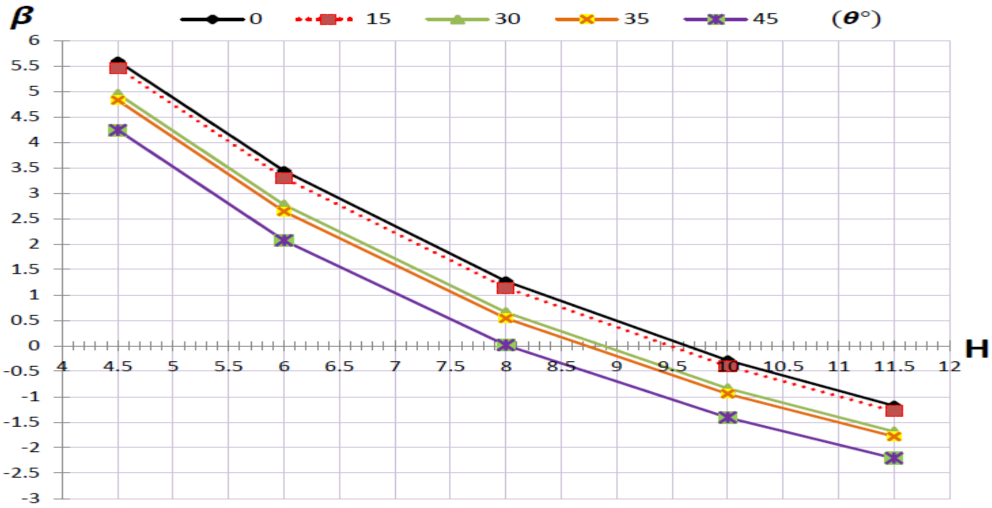
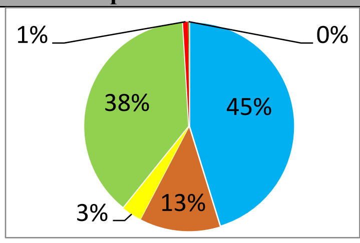


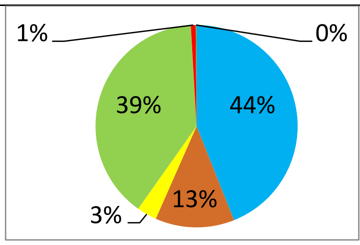
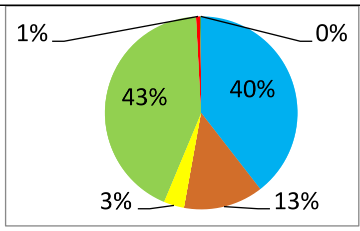
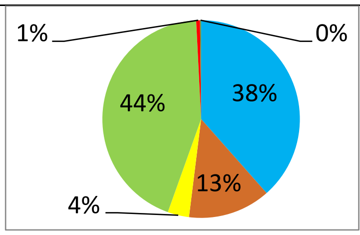
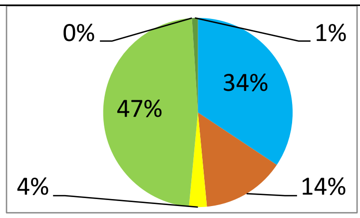
Figure 3 The Reliability Index with Heights for G1

4.2. Important Percentage Values for G1

When H=4.5m, θ° = 0 the random variable for ft is 45% this means that (ft) ratio affect the equation of the limit state in random variables equal 45%, then comes the least important (H)the ratio of affected equal 38%, while (H1, qs and ***θ***) the ratio of affected equally are very low. On the other hand, we note that the (ft) decreases with increasing heights (4.5, 6, 8, 10 11.5)
while the random variable (H) is a high-impact on the limit state that up to 78% at the height of 11.5m, the Output Result of Reliability Analysis for G1 are listed in table 5.

Table 4 The Output Result of Reliability Analysis for G1

H	θ	β	P_f	RV	Importance	
4.5	0°	5.59	1.13e-08	ft	45 %	
				Φ	13 %	
				γ	3 %	
				H	38 %	
				qs	1 %	
				H1	0 %	

4.5	15°	5.46	2.367e-08	ft	44 %	
				Φ	13 %	
				γ	3 %	
				H	39 %	
				qs	0 %	
				H1	1 %	
4.5	30°	4.95	3.595e-07	ft	40 %	
				Φ	13 %	
				γ	3 %	
				H	43 %	
				qs	0 %	
				H1	1 %	
4.5	35°	4.828	6.828e-07	ft	38 %	
				Φ	13 %	
				γ	3 %	
				H	44 %	
				qs	0 %	
				H1	1 %	
4.5	45°	4.24	1.1e-05	ft	34 %	
				Φ	14 %	
				γ	4 %	
				H	47 %	
				qs	0 %	
				H1	1 %	

4.3. Failure by Bending G2

This analysis considers the failure mode named "Failure by bending" which is the failure by bending of the anchor rod. The limit state equation for G2 is:

$$ {}_2 = M_R - M_B \leq 0 \qquad (20)$$

Where MB is the total applied moment?

$$M_B = \frac{13}{54} K_a \gamma H {H_1}^2 \qquad (21)$$

And MR is the total resistance moment:

$$M_R = Z \times F_b \qquad (22)$$

$$M_R = \frac{\pi R^3}{4} \times 1000 \times (0.55\ F_y) \qquad (23)$$

$$M_R = 432\ R^3\ F_y \qquad [34]$$

substuit equations (21) and [36] in equation (20):

$$ {}_2 = \left[\left(432\ R^3\ F_y\right) - \left(0.24\ K_a \gamma H {H_1}^2\right)\right] \leq 0 \qquad (25)$$

Table 6 shows the result after applying the same procedure.

Table 5 Reliability index (β) and Probability of failure [37] for G2

H	β	P_f
4.5	2.848	2.195e-3
6	2.743	3.04e-3
8	2.615	4.45e-3
10	2.5	6.21e-3
11.5	2.42	7.76e-3

It can be deduced from Figures (5 and 6) that all heights of retaining structure are suitable.

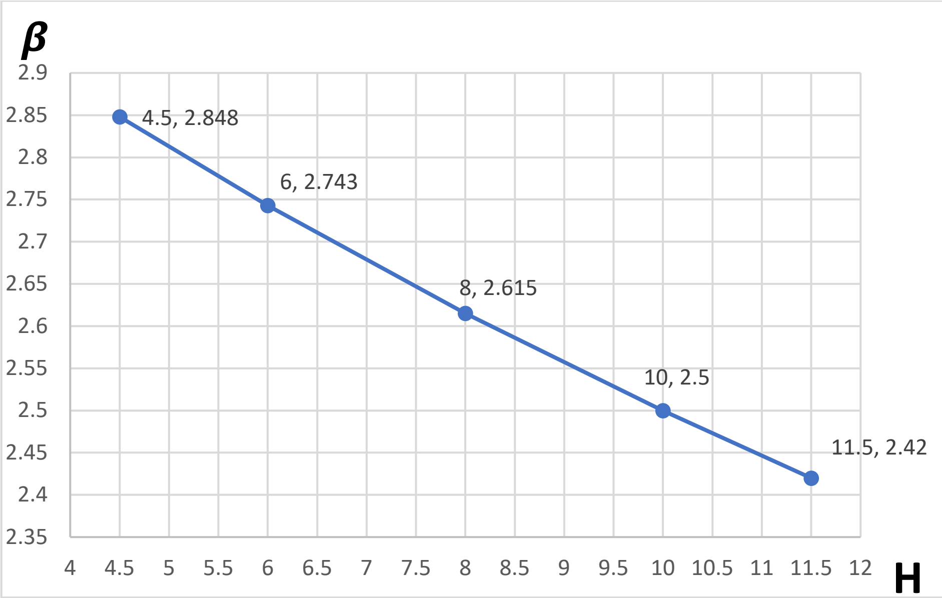


Figure 4 The Reliability Index with Heights Retaining Structure for G2

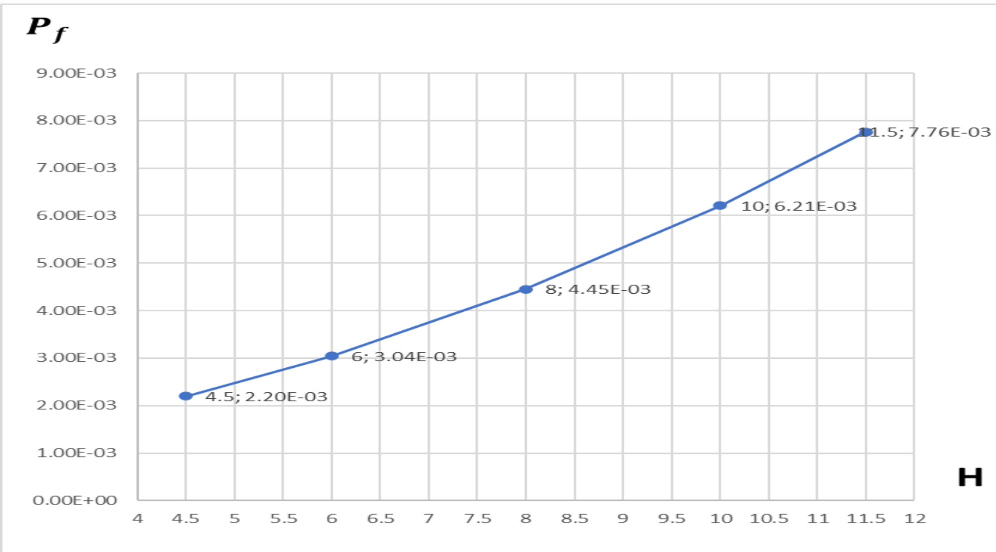
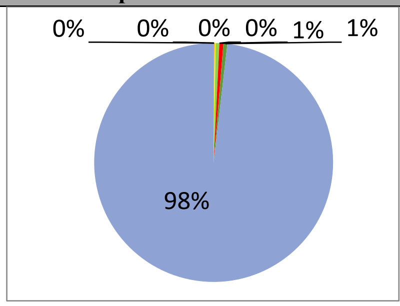
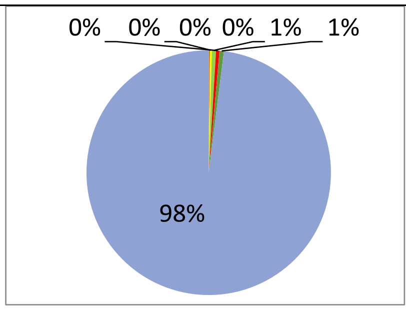
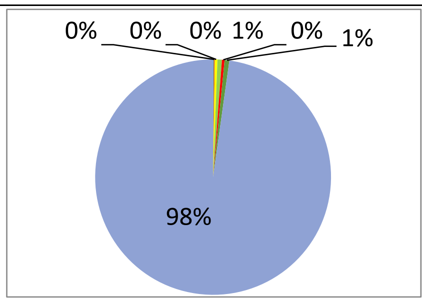
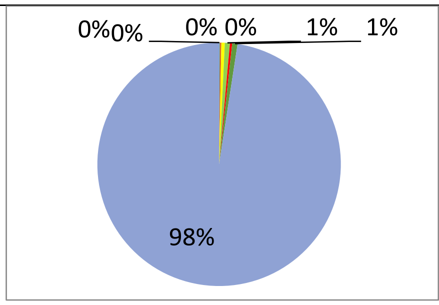
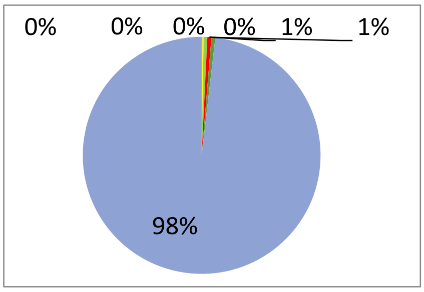


Figure 5 Probability of Failure with Heights Retaining Structure for G2

4.4. Important Percentage Values for G2

For Bending Failure case, the random variable R =98% means that (R) ratio affect the equation of the limit state in random variables equals 98%, in other words, it has a high impact on the design limit state. The output results of reliability analysis for G2 are listed in table 7 below.

Table 6 Output Results of Reliability Analysis For G2

<table>
<tr><th>H</th><th>β</th><th>P_f</th><th>RV</th><th colspan="2">Importance</th></tr>
<tr><td rowspan="7">4.5</td><td rowspan="7">2.848</td><td rowspan="7">2.195e-3</td><td>γ</td><td>0.03%</td><td rowspan="7">
</td></tr>
<tr><td>Φ</td><td>0.08%</td></tr>
<tr><td>H</td><td>0.16%</td></tr>
<tr><td>H1</td><td>0.50%</td></tr>
<tr><td>qs</td><td>0.54%</td></tr>
<tr><td>Fy</td><td>0.53%</td></tr>
<tr><td>R</td><td>98.15%</td></tr>
<tr><td rowspan="7">6</td><td rowspan="7">2.743</td><td rowspan="7">3.04e-3</td><td>γ</td><td>0.04%</td><td rowspan="7">
</td></tr>
<tr><td>Φ</td><td>0.13%</td></tr>
<tr><td>H</td><td>0.24%</td></tr>
<tr><td>H1</td><td>0.55%</td></tr>
<tr><td>qs</td><td>0.45%</td></tr>
<tr><td>Fy</td><td>0.58%</td></tr>
<tr><td>R</td><td>98.01%</td></tr>
<tr><td rowspan="7">8</td><td rowspan="7">2.615</td><td rowspan="7">4.45e-3</td><td>γ</td><td>0.06%</td><td rowspan="7">
</td></tr>
<tr><td>Φ</td><td>0.18%</td></tr>
<tr><td>H</td><td>0.35%</td></tr>
<tr><td>H1</td><td>0.61%</td></tr>
<tr><td>qs</td><td>0.36%</td></tr>
<tr><td>Fy</td><td>0.65%</td></tr>
<tr><td>R</td><td>97.80%</td></tr>
<tr><td rowspan="7">10</td><td rowspan="7">2.5</td><td rowspan="7">6.21e-3</td><td>γ</td><td>0.07%</td><td rowspan="7">
</td></tr>
<tr><td>Φ</td><td>0.23%</td></tr>
<tr><td>H</td><td>0.45%</td></tr>
<tr><td>H1</td><td>0.67%</td></tr>
<tr><td>qs</td><td>0.30%</td></tr>
<tr><td>Fy</td><td>0.71%</td></tr>
<tr><td>R</td><td>97.56%</td></tr>
<tr><td rowspan="7">11.5</td><td rowspan="7">2.42</td><td rowspan="7">7.76e-3</td><td>γ</td><td>0.09%</td><td rowspan="7">
</td></tr>
<tr><td>Φ</td><td>0.27%</td></tr>
<tr><td>H</td><td>0.52%</td></tr>
<tr><td>H1</td><td>0.71%</td></tr>
<tr><td>qs</td><td>0.26%</td></tr>
<tr><td>Fy</td><td>0.76%</td></tr>
<tr><td>R</td><td>97.39%</td></tr>
</table>

4.5. Comparison between the limit states

The comparison between the two failure modes by the mean of: (β, P_f with two angles for anchor). The most dangerous failure mode on the structure safety is to be taken primarily into consideration in the design.

Comparison when Θ= 0 º:

In figure 7 and table 8, the over, the critical and the suitable height of retaining structure, and we deduce the critical failure mode for a horizontal anchor rod is obtained.

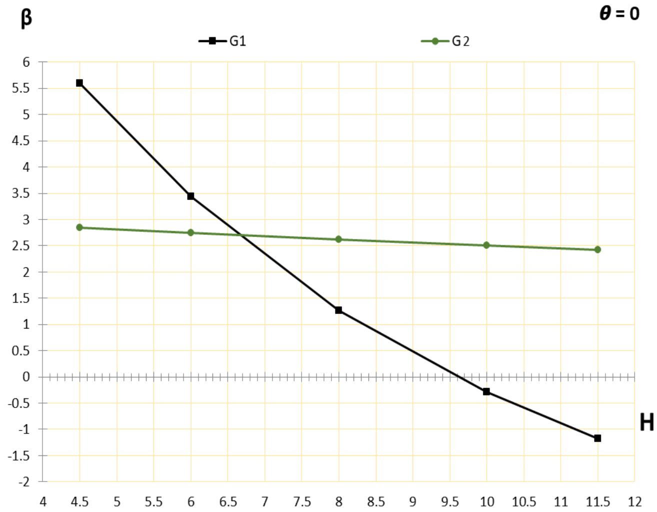


Figure 6 Comparison G1 and G2 at Ө= 0 º

Table 7 the deduce heights for retaining structure

G	Over	Suitable	Critical
G1	H < 6	(6 – 7.5)	H > 7.5
G2	For all H		

And the critical failure mode is the tensile failure of the tendon (G1) that is the most critical among the two failure modes.

Comparison when Ө= 45 º:

In figure 8 and table 9, the over, the critical and the suitable height of retaining structure, and we deduce the critical failure mode for inclined anchor rod is obtained.

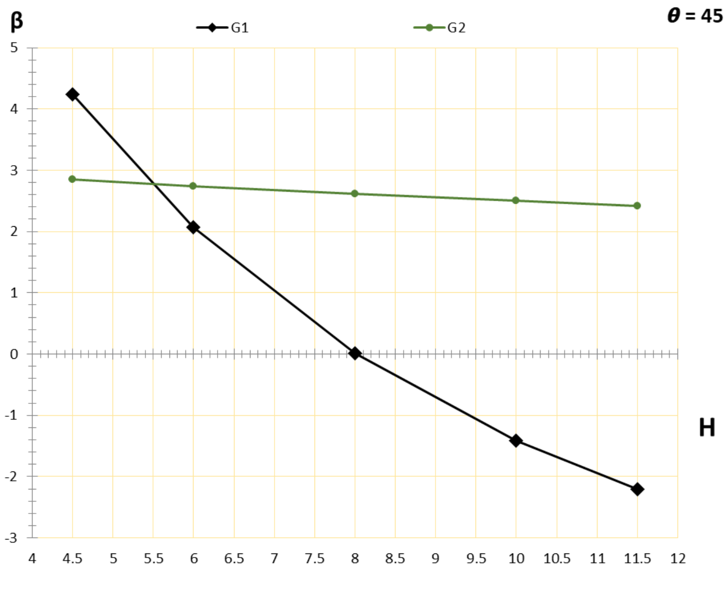


Figure 7 Comparison of G1 and G2 at Ө= 45 º

Table 8 The deduce heights for retaining structure

G	Over	Suitable	Critical
G1	H < 5	(5– 6)	H > 6
G2	For all H		

And the critical failure mode is the tensile failure of the tendon (G1) that is the most critical among the two failure modes.

5. CONCLUSIONS

The reliability problems on two cases of retaining wall has been addressed (i.e. Tensile failure of a tendon (G1) and Failure by bending (G2) to estimate their reliability index and determine their failure probability. The results obtained by the combination of the continuous random variables' laws show that the method for estimating probability distributions used in the first approach approximate the real statistical distribution of the random variable correctly.

The analyses demonstrated that the reliability index β and probability of failure [37] are the most important parameter in the reliability analysis. Also, the suitable (H) for the retaining structure (for all angles ϴ) equals 6 m and the most critical angle is ϴ= 45º to prevent the failure by tensile of the tendon. At the same time, the bending failure reliability analysis showed that all heights of retaining structure are suitable. After comparing the two cases, it was found that (G1) is more dangerous than (G2).

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