Comparative study of seismic and non-seismic analysis of a soil slope to develop correlations for factor of safety considering horizontal and vertical seismic coefficients

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Abstract: Seismic and non-seismic analysis of any engineering project always gives different results. A soil slope is analysed in this research and both seismic and non-seismic analysis is performed to know about the difference in the factor of safety values. Correlations are developed between both these cases. These correlations are applicable for homogenous slopes only.

1. Introduction
Stability of any structure depends mainly on the structure internal strength and loads applied on it. If the applied loads exceed the strength of the structure, it may fail and damaged. This statement is applied for any structure whether concrete or made of soil. In this paper, the concern is about soil slopes. Whenever a highway is constructed in hilly areas or an earth fill dam is constructed, the slope stability analysis is performed and the factor of safety is calculated. The factor of safety mainly depends on soil properties and the slope layout etc. If the factor of safety is less, then it is stabilized by different ways such as changing the slope layout or inserting nails to increase the stability [1-3].

2. Literature Survey
Some of the researchers claim that the vertical seismic effect is very less and therefore can be neglected while other researchers claim that the vertical effect must also be considered to know about the actual response [4-8]. In this paper both the horizontal and vertical seismic coefficients are considered and correlations are developed between both the cases. There are many other researchers who provided very useful results in this area [9-14]. The plus point of this paper is that a comparison is done between seismic and non-seismic analysis and researchers can get a clear idea for any slope stability project to know about the seismic and non-seismic factor of safety in homogenous slopes.

There are many ways to check the stability of any slope. Such as it can be analysed using limit equilibrium methods or finite element methods. Also the analysis may be 2 dimensional or 3 dimensional. The simplest way is 2 dimensional limit equilibrium method. This limit equilibrium 2 dimensional method is used in the paper to calculate the seismic and non-seismic factor of safety for a predefined soil slope.

3. Methodology
Keeping the past research in consideration, this work is done in four stages:

- Non-Seismic analysis and calculated the factor of safety
• Analysis with considering Horizontal Seismic Coefficient (HSC) and ignoring vertical effect
• Analyse with considering Vertical Seismic Coefficient (VSC) and ignoring horizontal effect
• Analyse with considering both horizontal and vertical seismic effects

Thirty six number of analysis was performed on a predefined slope. The angle of repose was varied from 30 to 45 degrees during this analysis. The horizontal seismic coefficient was 0.05 minimum and 0.15 maximum as recommended in the paper [15]. While the vertical seismic coefficients are in range of 0.0125 to 0.05.

A limit equilibrium software is used in this analysis namely slide. The variation of factor of safety is provided in graphical form for all the cases.

Figure 1 shows the slope model used in this analysis:

Figure 1. Slope model

Cohesion range is 11 kN/m$^2$ to 13 kN/m$^2$.
Angle of repose range is 30 to 45 with five degrees interval.
Unit weight is 14 kN/m$^3$.
Angle of internal friction range is 31 to 33 degrees.
Horizontal seismic coefficient is 0.05, 0.10, and 0.20
Vertical seismic coefficient is 0.012, 0.25 and 0.05.
Table 1 shows the summary of material properties and the factor of safety achieved in all the cases.
Table 1. Material properties and analysis details

| Case Number | Cohesion (kN/m²) | Angle of Repose (AOR) | Unit Weight (kN/m³) | Friction angle (ϕ) | Horizontal Coefficient | Vertical Coefficient | Non-Seismic Factor of Safety (FS) | Seismic Factor of Safety (FS) |
|-------------|------------------|----------------------|--------------------|-------------------|------------------------|-----------------------|----------------------------------|-------------------------------|
| 1           | 11               | 30                   | 14                 | 31                | 0.05                   | 0                     | 1.631                            | 1.451                         |
| 1           | 12               | 30                   | 15                 | 32                | 0.10                   | 0                     | 1.690                            | 1.348                         |
| 1           | 13               | 30                   | 16                 | 33                | 0.20                   | 0                     | 1.750                            | 1.145                         |
| 2           | 11               | 35                   | 14                 | 31                | 0.05                   | 0                     | 1.539                            | 1.397                         |
| 2           | 12               | 35                   | 15                 | 32                | 0.10                   | 0                     | 1.590                            | 1.317                         |
| 2           | 13               | 35                   | 16                 | 33                | 0.20                   | 0                     | 1.641                            | 1.144                         |
| 3           | 11               | 40                   | 14                 | 31                | 0.05                   | 0                     | 1.431                            | 1.315                         |
| 3           | 12               | 40                   | 15                 | 32                | 0.10                   | 0                     | 1.477                            | 1.252                         |
| 3           | 13               | 40                   | 16                 | 33                | 0.20                   | 0                     | 1.522                            | 1.101                         |
| 4           | 11               | 45                   | 14                 | 31                | 0.05                   | 0                     | 1.295                            | 1.195                         |
| 4           | 12               | 45                   | 15                 | 32                | 0.10                   | 0                     | 1.336                            | 1.140                         |
| 4           | 13               | 45                   | 16                 | 33                | 0.20                   | 0                     | 1.377                            | 1.010                         |
| 5           | 11               | 30                   | 14                 | 31                | 0.0125                 | 0.0125                | 1.631                            | 1.628                         |
| 5           | 12               | 30                   | 15                 | 32                | 0.025                  | 0.025                 | 1.690                            | 1.683                         |
| 5           | 13               | 30                   | 16                 | 33                | 0.05                   | 0.05                  | 1.750                            | 1.735                         |
| 6           | 11               | 35                   | 14                 | 31                | 0.0125                 | 0.0125                | 1.539                            | 1.533                         |
| 6           | 12               | 35                   | 15                 | 32                | 0.025                  | 0.025                 | 1.590                            | 1.578                         |
| 6           | 13               | 35                   | 16                 | 33                | 0.05                   | 0.05                  | 1.641                            | 1.616                         |
| 7           | 11               | 40                   | 14                 | 31                | 0.0125                 | 0.0125                | 1.431                            | 1.425                         |
| 7           | 12               | 40                   | 15                 | 32                | 0.025                  | 0.025                 | 1.477                            | 1.463                         |
| 7           | 13               | 40                   | 16                 | 33                | 0.05                   | 0.05                  | 1.522                            | 1.495                         |
| 8           | 11               | 45                   | 14                 | 31                | 0.025                  | 0.025                 | 1.295                            | 1.289                         |
| 8           | 12               | 45                   | 15                 | 32                | 0.025                  | 0.025                 | 1.336                            | 1.324                         |
| 8           | 13               | 45                   | 16                 | 33                | 0.05                   | 0.05                  | 1.377                            | 1.353                         |
| 9           | 11               | 30                   | 14                 | 31                | 0.05                   | 0.0125                | 1.631                            | 1.450                         |
| 9           | 12               | 30                   | 15                 | 32                | 0.10                   | 0.025                 | 1.690                            | 1.349                         |
| 9           | 13               | 30                   | 16                 | 33                | 0.20                   | 0.05                  | 1.750                            | 1.156                         |
| 10          | 11               | 35                   | 14                 | 31                | 0.05                   | 0.0125                | 1.539                            | 1.393                         |
| 10          | 12               | 35                   | 15                 | 32                | 0.10                   | 0.025                 | 1.590                            | 1.312                         |
| 10          | 13               | 35                   | 16                 | 33                | 0.20                   | 0.05                  | 1.641                            | 1.143                         |
| 11          | 11               | 40                   | 14                 | 31                | 0.05                   | 0.0125                | 1.431                            | 1.311                         |
| 11          | 12               | 40                   | 15                 | 32                | 0.10                   | 0.025                 | 1.477                            | 1.245                         |
| 11          | 13               | 40                   | 16                 | 33                | 0.20                   | 0.05                  | 1.522                            | 1.098                         |
| 12          | 11               | 45                   | 14                 | 31                | 0.05                   | 0.0125                | 1.295                            | 1.191                         |
| 12          | 12               | 45                   | 15                 | 32                | 0.10                   | 0.025                 | 1.336                            | 1.134                         |
| 12          | 13               | 45                   | 16                 | 33                | 0.20                   | 0.05                  | 1.377                            | 1.004                         |
4. Results and Discussions
Figure 2 shows the factor of safety graph in case when only horizontal seismic coefficient are considered and the vertical seismic coefficient is kept zero.
Figure 3 shows the factor of safety graph in case when only vertical seismic coefficient are considered and the horizontal seismic coefficient is kept zero.
Figure 4 shows the factor of safety graphs in case both horizontal seismic coefficient as well as vertical seismic coefficient are considered.

![Factor of Safety graph in case HSC is considered and VSC is kept zero](image1)

![Factor of Safety graph in case VSC is considered and HSC is kept zero](image2)

![Factor of Safety graph in case both HSC and VSC are considered](image3)

Figure 2. Factor of Safety graph in case HSC is considered and VSC is kept zero
Figure 3. Factor of Safety graph in case VSC is considered and HSC is kept zero

Figure 4. Factor of Safety graph in case both HSC and VSC is considered
Case 1: Considering HSC and keeping VSC as zero
From figure 2, the final mean equation for the factor of safety came out to be:

\[ SFS = -2.4145 \times NSFS + 4.9285 \] (1)

Applicability of this equation is 95.40%.

Case 2: Considering VSC and keeping HSC as zero
From figure 3, the final mean equation for factor of safety came out to be:

\[ SFS = 0.8157 \times NSFS + 0.2620 \] (2)

Applicability of this equation is 99.81%.

Case 3: Considering both HSC and VSC
From figure 4, the final mean equation in case of HSC came out to be:

\[ SFS = -2.3854 \times NSFS + 4.8759 \] (3)

Applicability of this equation is 95.84%.

5. Conclusions
Equation 1, 2 and 3 can be used to find out the factor of safety in different cases, such as to consider seismic coefficients or ignoring it. These equations are applicable for homogenous soil. A 3D analysis with non-homogenous type of soil is recommended for future work to get more clear understanding of the factor of safety in both the cases. Moreover finite element analysis is also recommended for future work to cross check the results and develop correlations.

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Appendices
HSC = Horizontal Seismic Coefficient
VSC = Vertical Seismic Coefficient
SFS = Seismic Factor of Safety
NSFS = Non-Seismic Factor of Safety
FS = Factor of Safety