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RESEARCH ARTICLE

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 analysis of soil slopes is required to get safe value for slope design. Especially in earthquake zones. Normally a variation in factor of safety values is observed in normal analysis of a slope where seismic coefficients are kept zero as compare to seismic analysis where seismic coefficients are considered in the analysis. In this research, seismic horizontal coefficients are used to find the factors of safety. Correlations are developed between factor of safety values and seismic coefficients. The correlation can be used to find the factor of safety in any slope stability project for a homogenous slope. The outcome of this work are the correlations. These correlations can be used to find the factor of safety values considering horizontal seismic coefficient, vertical seismic coefficient and both.

KEYWORDS

Factor of safety, Seismic analysis, Correlations, Slope stability, Seismic coefficients.

1. INTRODUCTION

In most of the engineering design projects, there are always two types of consideration. Design with or without seismic effects. The seismic analysis are always different than the normal non-seismic analysis. The regions where earthquake and ground vibration is of much concern, the seismic analysis is having more importance compare to the regions where earthquakes are very rare and in low concentration. This paper is related to the seismic analysis of a soil slope.

2. LITERATURE SURVEY

The influence of soil strength on the probability of failure of slopes using conventional limit equilibrium slip circle analysis has been explored by (Li and Lumb, 1987; Chowdhury and Xu, 1993; Low et al., 1998; Hong and Roh, 2008). The same analysis is done using seismic horizontal and vertical coefficients. Regarding the consideration of horizontal and vertical seismic effects, it is a subject of debate between researchers. 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 (Gazetas et al., 2009; Sarma, 2009; Zhao et al., 2016; Ling and Mohri, 1997; Zhang et al., 2013). Keeping the past research in consideration, it is therefore decided to work on this subject with following steps:

- Analyse 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

3. METHODOLOGY

Twenty-four 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 (Cristiano, 2004). 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:

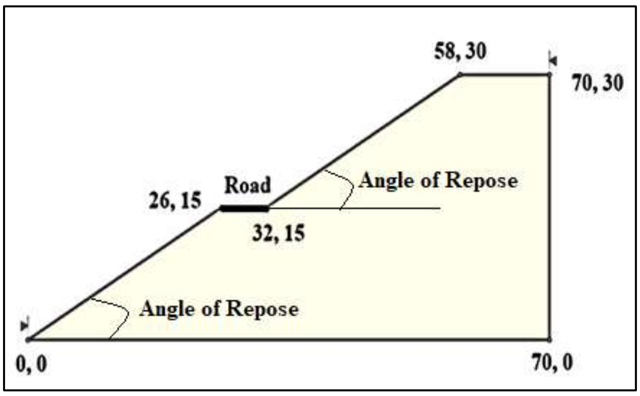

Figure 1: Slope model

Cohesion of the material is kept constant as 11 kN/m². Angle of repose range is 30 to 45 with five degrees interval. Unit weight is 14 kN/m³. Angle

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of internal friction is 31 degrees. Horizontal seismic coefficient is 0.05, 0.10, 0.20 and 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

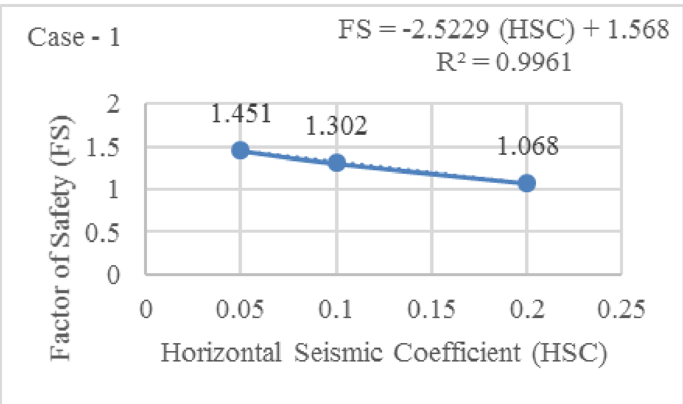
Case Number (M)	Cohesion (kN/m²)	Angle of Repose (AOR)	Unit Weight (kN/m³)	Friction angle (ϕ)	Horizontal coefficient	Vertical Coefficient	Factor of Safety (FS)
1	11	30	14	31	0.05	0	1.451
1	11	30	14	31	0.10	0	1.302
1	11	30	14	31	0.20	0	1.068
2	11	35	14	31	0.05	0	1.397
2	11	35	14	31	0.10	0	1.275
2	11	35	14	31	0.20	0	1.075
3	11	40	14	31	0.05	0	1.315
3	11	40	14	31	0.10	0	1.213
3	11	40	14	31	0.20	0	1.034
4	11	45	14	31	0.05	0	1.195
4	11	45	14	31	0.10	0	1.105
4	11	45	14	31	0.20	0	0.950
5	11	30	14	31	0	0.0125	1.628
5	11	30	14	31	0	0.025	1.624
5	11	30	14	31	0	0.05	1.617
6	11	35	14	31	0	0.0125	1.533
6	11	35	14	31	0	0.025	1.527
6	11	35	14	31	0	0.05	1.516
7	11	40	14	31	0	0.0125	1.425
7	11	40	14	31	0	0.025	1.418
7	11	40	14	31	0	0.05	1.405
8	11	45	14	31	0	0.0125	1.289
8	11	45	14	31	0	0.025	1.283
8	11	45	14	31	0	0.05	1.273
9	11	30	14	31	0.05	0.0125	1.450
9	11	30	14	31	0.10	0.025	1.302
9	11	30	14	31	0.20	0.05	1.078
10	11	35	14	31	0.05	0.0125	1.393
10	11	35	14	31	0.10	0.025	1.270
10	11	35	14	31	0.20	0.05	1.074
11	11	40	14	31	0.05	0.0125	1.311
11	11	40	14	31	0.10	0.025	1.207
11	11	40	14	31	0.20	0.05	1.032
12	11	45	14	31	0.05	0.0125	1.191
12	11	45	14	31	0.10	0.025	1.099
12	11	45	14	31	0.20	0.05	0.947

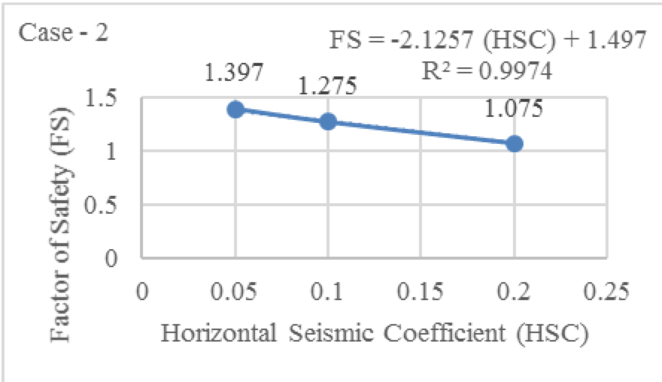
4. RESULTS AND DISCUSSIONS

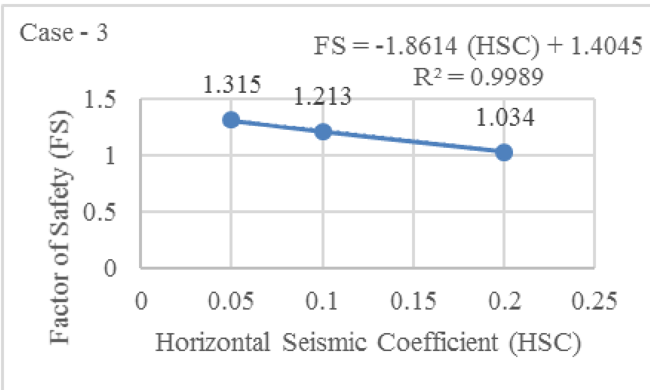
Figure 2 shows the factor of safety graph in case when only horizontal seismic coefficient are considered and the vertical seismic coefficient is kept zero.

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.







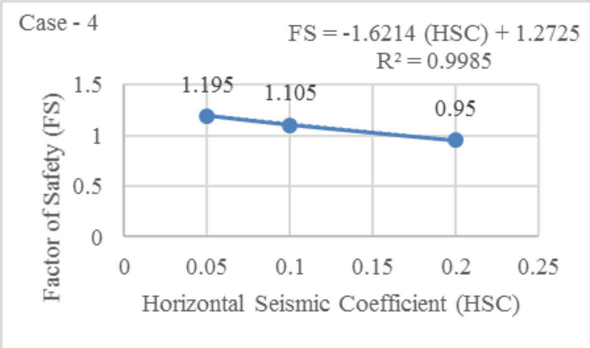
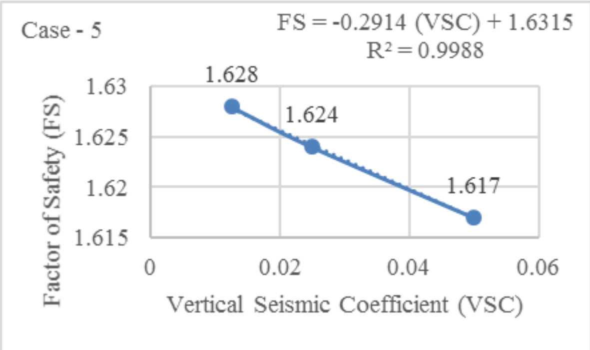
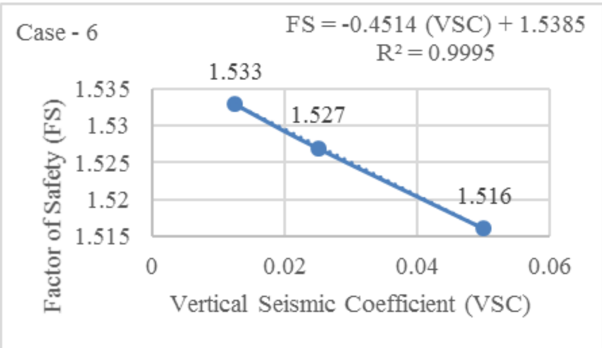
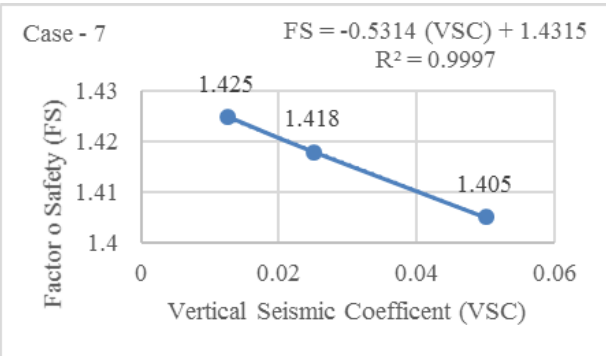


Figure 2: Factor of Safety graph in case HSC is considered and VSC is kept zero







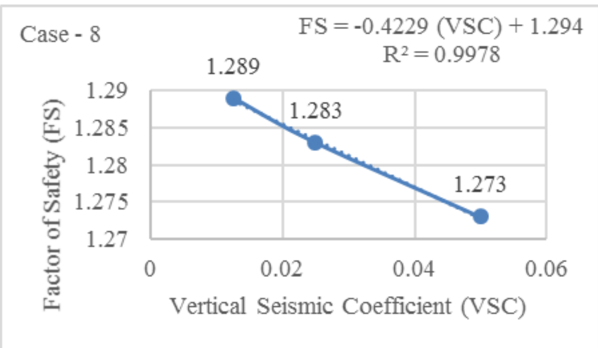
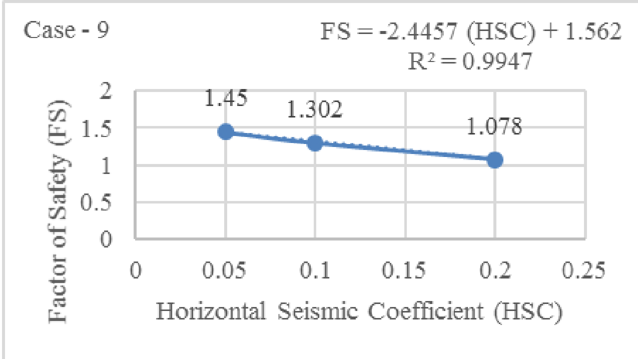
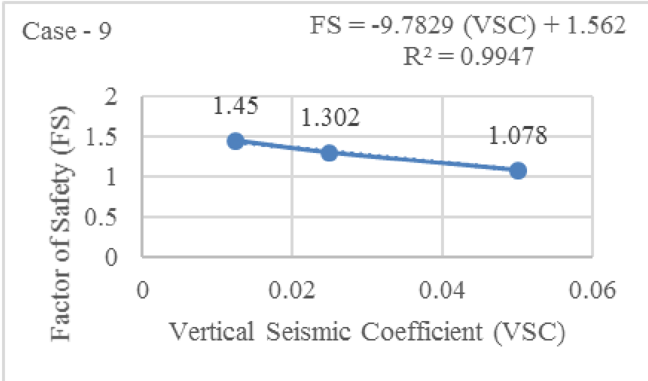
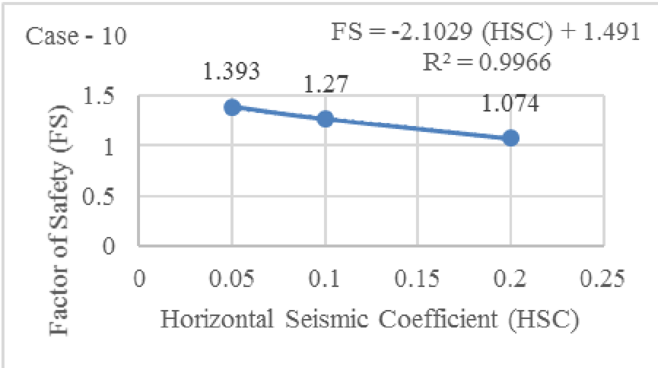
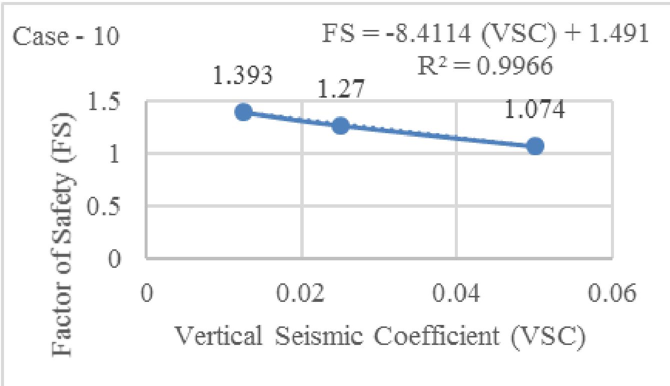


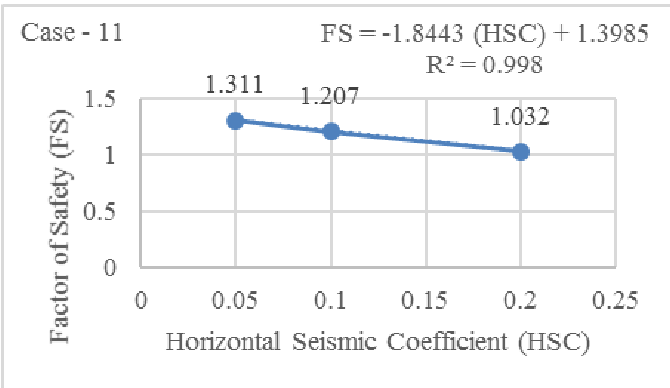
Figure 3: Factor of Safety graph in case VSC is considered and HSC is kept zero











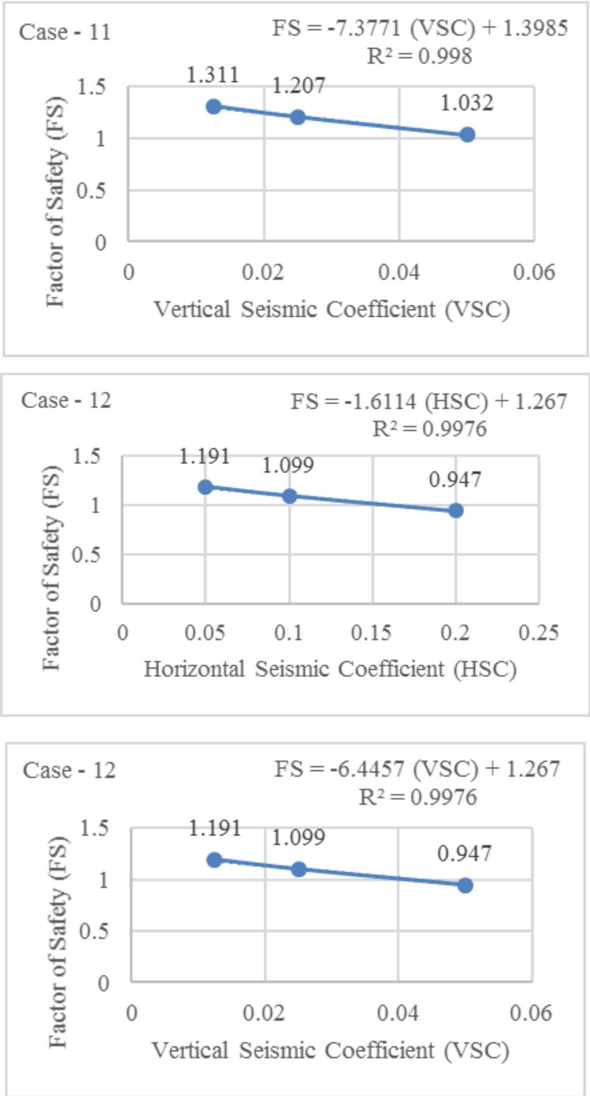


Figure 4: Factor of Safety graph in case both HSC and VSC is considered

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:

FS = - 2.032 * HSC + 1.4355 (1)

Applicability of this equation is 99.77 %.

Case 2: Considering VSC and keeping HSC as zero

From figure 3, the final mean equation for factor of safety came out to be:

FS = - 0.4243 * VSC + 1.4739 (2)

Applicability of this equation is 99.89 %

Case 3: Considering both HSC and VSC

From figure 4, the final mean equation in case of HSC came out to be:

FS = - 2 * HSC + 1.430 (3)

Applicability of this equation is 99.67 %.

While from same figure 4, the final mean equation in case VSC came out to be:

FS = - 8 * VSC + 1.43 (4)

Applicability of this equation is 99.67 %.

5. CONCLUSIONS

Equation 1 and 2 can be used to find out the factor of safety in case only HSC and VCS is considered respectively. Equation 3 and 4 can be used for calculating factor of safety in case both HSC and VSC are considered. In further research, these results can also be compared with normal analysis where seismic coefficients are kept zero to get a clear understanding of the difference between seismic and non-seismic analysis.

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