Data Article

Safety-factor dataset for high embankments determined with different analytical methods

Milena Mesa-Lavista [a,*], José Álvarez-Pérez [a],
Eduardo Tejeda-Piusseaut [b], Francisco Lamas-Fernández [c]

[a] *Universidad Autónoma de Nuevo León (UANL), Facultad de Ingeniería Civil (FIC), Departamento de Estructuras, Ave. Universidad, s/n CP. 66455, San Nicolás de los Garza, Nuevo León, Mexico*
[b] *Universidad Técnica de Manabí, Facultad de Ciencias Matemáticas, Físicas y Químicas, Ecuador*
[c] *Universidad de Granada, Departamento de Ingeniería Civil, ETSICCP, Granada, Spain*

A B S T R A C T

Slope-stability analysis is one of the parameters in the design of road embankments that the designer must consider in order to ensure stable and safe construction. The technical standards recommend slopes to heights of 12 m, depending on the soil types and the topography. In the present work, the limit equilibrium methods (Fellenius, Bishop, Janbu, Morgensten-Price) and the finite element method are used to determine the safety factor of road embankments for different slopes flanking the road. Five embankment heights were simulated: 6 m, 12 m, 18 m, 24 m, and 30 m. The dataset compiled can be used for modeling embankments.

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* Corresponding author.
  E-mail address: mmesal@uanl.edu.mx (M. Mesa-Lavista).
  Social media: 🐦 (M. Mesa-Lavista), 🐦 (F. Lamas-Fernández)

Specifications Table

Subject	Civil and Structural Engineering
Specific subject area	Safety factor of road embankment
Type of data	Tables and Figures
How data were acquired	The data was generated by numerical simulation in GeoStudio Software.
Data format	Raw and primary processed data
Parameters for data collection	Data were collected via the GeoStudio Software by using the limit equilibrium methods (Fellenius, Bishop, Janbu, and Morgensten-Price) and finite element method
Description of data collection	For data collection, several factors were taken into consideration, including the stress-stress state in each model, the yielding in the foundation and embankment, and the value of the safety factor. In this work, five embankment heights were modeled: 6 m, 12 m, 18 m, 24 m, and 30 m. Each model had different slopes as well as different soils in the core of the embankment and foundation. In addition, five methods were used to calculate the safety factor: Fellenius, Bishop, Janbu, Morgensten-Price, and the finite element method.
Data source location	Institution: Universidad Autónoma de Nuevo León, Instituto de Ingeniería Civil. City: Nuevo León Town: San Nicolás de los Garza Region: Ciudad Universitaria Country: Mexico (25°44′00.07″ N, 100°18′22.55″ O)
Data accessibility	http://dx.doi.org/10.17632/59j9bvsrxt.2
Related research article	Mesa-Lavista, M. Tejeda-Piusseaut, E., Analysis of slope stability in embankment still 18 m heights through the limit equilibrium methods and the finite element method (In Spanish), Revista cubana de ingeniería. IX (2019) 49-56. https://rci.cujae.edu.cu/index.php/rci/article/view/519 [1]

Value of the Data

- The dataset shows the values of safety factors determined for varying embankment heights, using different methods.
- The data can be used for road-embankment design and railway engineering.
- In embankment design, with soils similar to those of the database, which are common in such structures, the safety-factor value is given by different methods and varying embankment heights, and these can be used for comparisons with other results.

1. Data Description

The dataset provides the results for the safety factor of embankment modeling at varying heights by using different methods. GeoStudio software has several modules, two of which were used to model the embankments of this work: SIGMA/W modulus [2] for establishing the stress-strain relationship and the SLOPE/W [3] modulus for determining the safety factor of the soil structures. The software offers five methods to determine the safety factor in embankment slopes, four being limit equilibrium methods (Fellenius, Bishop, Janbu, and Morgensten-Price), and the other being the finite element method. This latter method considers the stress-strain in the embankment in calculating the safety factor, and therefore the safety-factor behavior in the dataset for this method differs from the others. Mohr-Coulomb was the constitutive model used. For load, the initial stress of foundation soil was used, the embankment characteristics were added, and finally the pavement load of 14 kPa on the embankment was considered.

The numeric model was calibrated and validated, and the foundation depth was defined by following the instructions in [1].

In the dataset from http://dx.doi.org/10.17632/59j9bvsrxt.2 the values of safety factor for 6 m, 12 m, 18 m, 24 m and, 30 m are provided. In addition, graphs illustrating the behavior of safety factors for each method and height are available and display the tabulated values.
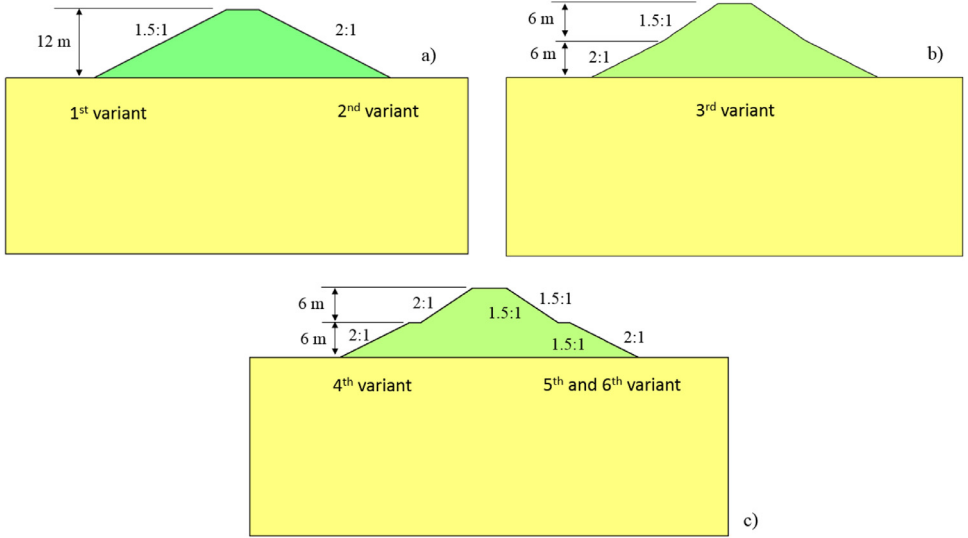
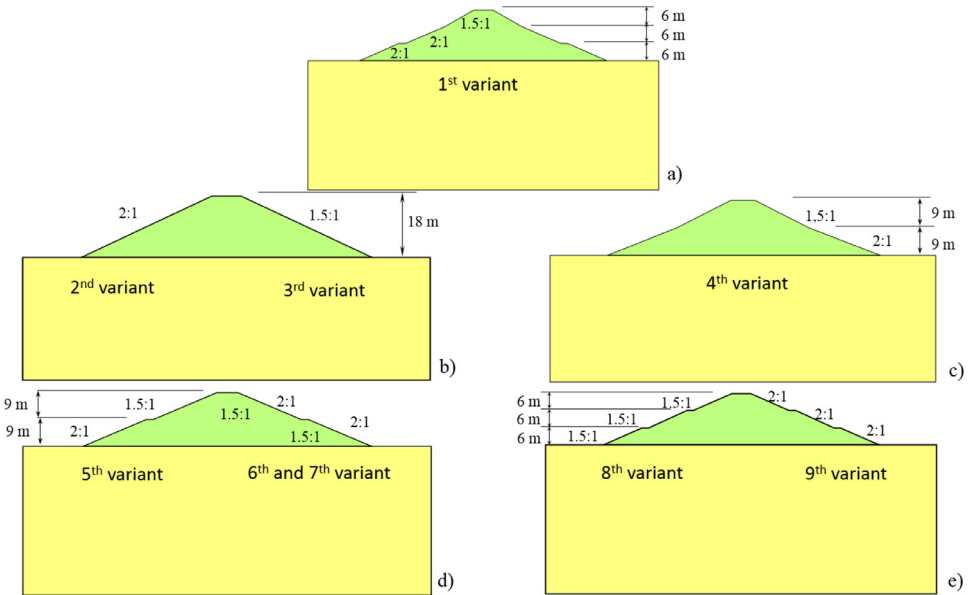**Fig. 1.** Variation of slope embankments 12 m high.

Fig. 2. Variation of slope embankments 18 m high.

Fig. 1 shows the different slopes used to model the embankment of 12 m high. Six variants were considered. For the 1st and 2nd variants (Fig. 1a), one slope was considered for each height, 1.5:1 and 2:1, respectively. In the 3rd variant (Fig. 1b), a change in slope was considered at 6 m high. For the other three variants (Fig. 1c), a berm 2 m wide was considered at 6 m high.

Fig. 2 presents all the variants used in embankments 18 m high. Fig. 2a shows that this embankment was divided into three-parts 6 m high each. The first 6 m have a slope of 2:1, a berm was modeled, and then two slopes of 2:1 and 1.5:1 were used for the upper 12 m. Fig. 2b

Table 1
Slopes for embankments 24 m high.

Height	24 m							1st variant
Slope	2:1							
Height	1st 12 m	Berm	2nd 12 m					2nd variant
Slope	2:1	2 m wide	2:1					
Height	1st 6 m	2nd 6 m	Berm	3rd 6 m	4th 6 m			3rd variant
Slope	2:1	1.5:1	2 m wide	2:1	1.5:1			
Height	1st 6 m	Berm	2nd 6 m	Berm	3rd 6 m	Berm	4th 6 m	4th variant
Slope	2:1	2 m wide	2:1	2 m wide	2:1	2 m wide	2:1	

Fig. 3. Variation of slope embankments 24 m high.

represents two ways of modeling the slopes, one with a slope of 2:1 and the other with a slope of 1.5:1, totaling 18 m high. Fig. 2c illustrates the modeling of an embankment with two slopes 9 m high, the lower one 2:1, and the higher one 1.5:1. Finally, Fig. 2d and e depict a four-way modeling of the embankment slopes measuring a total of 18 m, with berm at each 9 m and 6 m, respectively.

Tables 1 and 2 show the slopes for embankments 24 m and 30 m high, respectively. For the embankment 24 m high, four variants were modeled, first with a slope of 2:1 in all cases, and second (Fig. 3a) with a berm at 12 m high. The third variant (Fig. 3c) was modeled with a berm only at 12 m high, with a slope change at 6 m high. The last variant (4th) had a berm at 6-m intervals. For the embankment 30 m high, three variants were modeled, the first variant (Fig. 4a) with a berm at 15 m high and the others with a change every 6 m (Fig. 4b and c).

Tables 3 and 4 show the physical and mechanical parameters of the soil employed in embankment and foundation modeling.

The dataset (http://dx.doi.org/10.17632/59j9bvsrxt.2) illustrates the results from the modeling of 900 simulations. Table 5 exemplifies a legend by colors for interpreting the results, where yellow tones represent the yielding of the embankment and the orange tones represent the yielding in the foundation. As the stress-strain was also considered in the models, the alteration/non-alteration in the stress-strain state were determined, as shown in Fig. 5. This figure corresponds to the embankment of 6 m high with slope 1:1, soil in embankment A-1, V.1, and the foundation with a California Bearing Ratio (CBR) = 3%. Because the stress and displacement field are altered, the numbers of Table 6 appear in red for that model. The numbers in *italics* correspond to the values of less than 1.5 of the safety factor. Values greater than 1.5 are acceptable safety factors. The underlined numbers signify that the safety-factor values are close to the limit number 1.5. Also, in Fig. 5 the embankment and the foundation are yielding, and therefore the text in Table 6 is highlighted in dark orange.

Table 2
Slopes for embankments 30 m high.

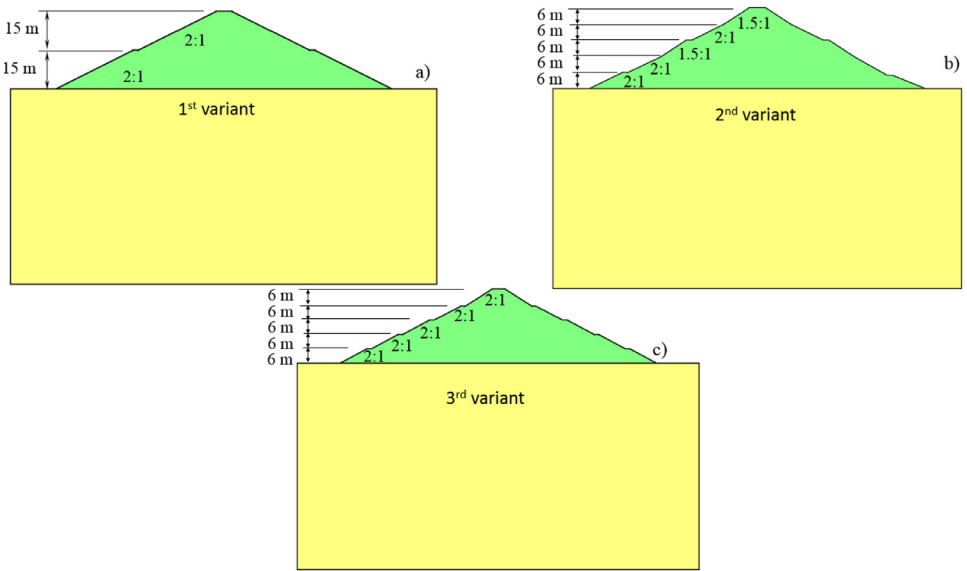| Height	1st 15 m	Berm	2nd 15 m							1st variant
Slope	2:1	2 m wide	2:1							
Height	1st 6 m	Berm	2nd 6 m	3rd 6 m	Berm	4th 6	5th 6 m			2nd variant
Slope	2:1	2 m wide	2:1	1.5:1	2 m wide	2:1	1.5:1			
Height	1st 6 m	Berm	2nd 6 m	Berm	3rd 6 m	Berm	4th 6	Berm	5th 6 m	3rd variant
Slope	2:1	2 m wide	2:1	2 m wide	2:1	2 m wide	2:1	2 m wide	2:1	

Fig. 4. Variation of slope embankments 30 m high.

Table 3
Physical and mechanical soil parameters considered for the core of the embankment.

AASHTO Classification	A-1			A-2			A-3			A-4		
Parameters	V.1	V.2	V.3	V.1	V.2	V.3	V.1	V.2	V.3	V.1	V.2	V.3
γ (kN/m³) Specific weight	21	22	23	20	21.5	23	20	20	20	18	20.5	23
w (%) Moisture	15	11	7	18	13.5	9	9	13.5	18	20	15	10
E (MPa) Deformation modulus	30	40	50	25	35	45	20	30	40	10	15	20
C (kPa) Cohesion	2	4	6	2	5	8	4	6	8	10	25	40
$\emptyset$ (°) Friction angle	30	35	40	30	35	40	30	35	40	25	30	35
μ (adim) Poisson's ratio	0.25	0.25	0.25	0.25	0.25	0.25	0.30	0.30	0.30	0.30	0.30	0.30
Θ (°) Dilatancy angle	4.50	5.25	6.00	4.50	5.25	6.00	4.50	5.25	6.00	3.75	4.50	5.25

Table 4
Physical and mechanical soil parameters considered for the foundation of the embankment.

California Bearing Ratio CBR (%)	Deformation modulus (kPa) $E_d = 6.5CBR^{0.65}$	Specific weight γ (kN/m³)	Poisson μ (adim)	Cohesion C (kPa)	Friction $\emptyset$ (°)	Dilatancy Θ (°)
15%	38,000	22.00		10	40	6.0
5%	18,500	20.00	0.30	20	30	4.5
3%	13,275	18.00		30	20	3.0

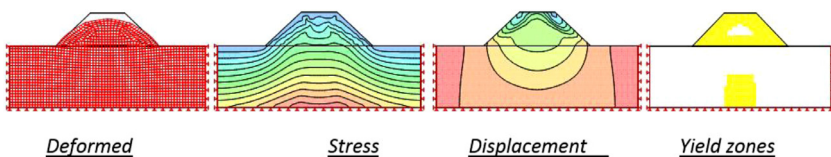*Deformed*   *Stress*   *Displacement*   *Yield zones*

Fig. 5. Stress-strain state for slope 1:1 measuring 6 m high.

Table 5
Color and analysis method legend for interpreting results from Table 6 and tables in the dataset.

	Yielding in the foundation	F	Fellenius method
	Yielding in the foundation and embankment	B	Bishop method
	Yielding embankment in 60%	J	Janbu method
	Yielding embankment less than 50%	MP	Morgensten-Price method
abc	alteration of the stress-strain state	FEM	Finite Element Method
abc	Security factor less than 1.5	a̲b̲c̲	Security factor close to 1.5

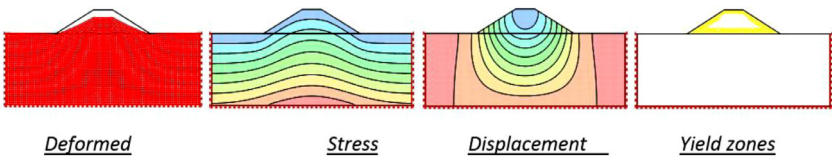Deformed　　　　　Stress　　　　Displacement　　　Yield zones

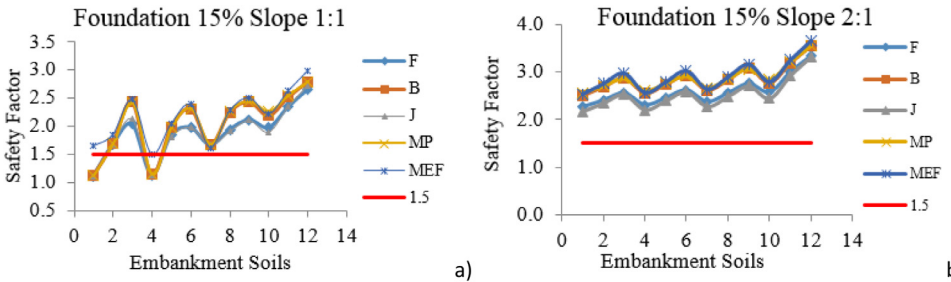**Fig. 6.** Stress-strain state for slope 2:1 measuring 6 m high.

Fig. 7. Safety-factor graphs taking into account the methods and soils used for embankments, 6 m high with 15% of CBR in the foundation (a) with slope 1:1 and, (b) with slope 2:1.

Fig. 6 represents the stress-strain state for the embankment 6 m high with a slope of 2:1 and CBR = 5%. The stress and displacement field do not change, and only the embankment is yielding and the values of safety factor are greater than 1.5. Furthermore, in Table 5, the initials for the method names used are shown.

All tables and figures in the dataset from http://dx.doi.org/10.17632/59j9bvsrxt.2 represent the values of safety factors for the embankments of 6 m, 12 m, 18 m, 24 m, and 30 m, taking into account the stress-strain relationship. Figures in the dataset, such as Fig. 7, represent the behavior of the safety factor for the different methods applied as well as for different soil in the embankment. For example, soil 1 on the x-axis represents the Soil A-1 V.1, soil number 2 represents the A-1 V.2, and so on to number 12, which represents the soil A-4 V.3 from Tables 3 and 6. These figures also have the limit of 1.5 defined. In Fig. 7a, with almost all methods the safety factor was under the limit for soils 1 and 4 (A-1 V.1 and A-2 V.1 respectively); see Table 6. However, in Fig. 7b, all safety-factor values for all methods were above 1.5.

Table 6
Embankment 6 m high.

H=6 m		Soil												
		A-1			A-2			A-3			A-4			
Slope	Method	V.1	V.2	V.3	V.1	V.2	V.3	V.1	V.2	V.3	V.1	V.2	V.3	
		1	2	3	4	5	6	7	8	9	10	11	12	
1:1	F	1.107	1.674	2.044	1.132	1.865	1.974	1.665	1.971	2.132	2.029	2.307	2.465	Foundation 3%
	B	1.122	1.687	2.368	1.147	1.976	2.259	1.673	2.253	2.416	2.233	2.461	2.622	
	J	1.106	1.673	2.084	1.132	1.842	1.983	1.663	1.939	2.127	1.95	2.313	2.534	
	MP	1.119	1.686	2.282	1.144	1.975	2.19	1.672	2.189	2.343	2.206	2.443	2.617	
	FEM	1.575	2.067	2.383	1.619	2.12	2.282	1.682	2.217	2.423	2.202	2.528	2.733	
	F	1.107	1.674	2.037	1.132	1.838	1.96	1.665	1.93	2.092	1.975	2.313	2.582	Foundation 5%
	B	1.122	1.687	2.38	1.147	1.976	2.264	1.673	2.234	2.41	2.2	2.479	2.721	
	J	1.106	1.673	2.072	1.132	1.82	1.971	1.663	1.907	2.094	1.898	2.331	2.678	
	MP	1.119	1.686	2.31	1.144	1.975	2.217	1.672	2.202	2.36	2.212	2.477	2.72	
	FEM	1.583	2.091	2.427	1.39	2.144	2.338	1.64	2.242	2.476	2.211	2.598	2.902	
	F	1.107	1.674	2.036	1.132	1.842	1.976	1.665	1.943	2.114	1.977	2.347	2.657	Foundation 15%
	B	1.122	1.687	2.43	1.147	1.976	2.307	1.673	2.245	2.434	2.187	2.514	2.782	
	J	1.106	1.673	2.125	1.132	1.808	1.976	1.663	1.902	2.104	1.895	2.348	2.726	
	MP	1.119	1.686	2.405	1.144	1.975	2.307	1.672	2.27	2.432	2.258	2.54	2.786	
	FEM	1.641	1.843	2.475	1.496	2.043	2.385	1.618	2.274	2.51	2.218	2.633	2.99	
1,5:1	F	1.886	1.988	2.193	1.936	2.037	2.145	1.99	2.144	2.31	2.205	2.503	2.626	Foundation 3%
	B	2.179	2.303	2.574	2.235	2.35	2.467	2.279	2.457	2.64	2.438	2.704	2.812	
	J	1.814	1.953	2.233	1.857	1.996	2.142	1.91	2.093	2.286	2.087	2.483	2.678	
	MP	2.12	2.226	2.481	2.175	2.273	2.381	2.223	2.38	2.549	2.405	2.675	2.803	
	FEM	2.153	2.316	2.694	2.2	2.379	2.57	2.252	2.482	2.724	2.424	2.786	2.973	
	F	1.898	2.006	2.249	1.944	2.057	2.179	2.006	2.162	2.331	2.206	2.556	2.792	Foundation 5%
	B	2.186	2.328	2.636	2.234	2.373	2.514	2.282	2.469	2.663	2.424	2.737	2.99	
	J	1.807	1.954	2.257	1.846	2.002	2.16	1.909	2.099	2.297	2.101	2.522	2.841	
	MP	2.178	2.298	2.553	2.226	2.341	2.465	2.274	2.436	2.611	2.436	2.732	2.99	
	FEM	2.181	2.36	2.778	2.217	2.424	2.632	2.285	2.525	2.774	2.44	2.837	3.128	
	F	1.935	2.06	2.322	1.974	2.109	2.253	2.038	2.205	2.38	2.256	2.645	2.971	Foundation 15%
	B	2.22	2.373	2.695	2.264	2.42	2.573	2.316	2.517	2.719	2.452	2.818	3.134	
	J	1.847	2.001	2.317	1.879	2.047	2.218	1.941	2.134	2.336	2.128	2.594	2.977	
	MP	2.276	2.398	2.661	2.318	2.443	2.569	2.366	2.539	2.712	2.519	2.848	3.143	
	FEM	2.22	2.417	2.84	2.254	2.483	2.703	2.338	2.578	2.834	2.479	2.916	3.292	
2:1	F	2.138	2.249	2.323	2.195	2.303	2.359	2.256	2.423	2.565	2.48	2.729	2.766	ndation
	B	2.41	2.551	2.704	2.47	2.603	2.73	2.52	2.723	2.94	2.696	2.969	3.02	
	J	2.037	2.187	2.315	2.084	2.236	2.351	2.143	2.343	2.534	2.339	2.679	2.79	
	MP	2.357	2.483	2.622	2.416	2.536	2.67	2.468	2.657	2.859	2.667	2.948	3.009	
	FEM	2.414	2.631	2.804	2.462	2.661	2.839	2.521	2.772	3.032	2.685	3.021	3.132	
	F	2.172	2.297	2.436	2.221	2.349	2.49	2.283	2.458	2.648	2.498	2.877	3.056	Foundation 5%
	B	2.443	2.601	2.766	2.496	2.651	2.811	2.551	2.76	2.978	2.706	3.06	3.309	
	J	2.081	2.241	2.411	2.123	2.29	2.464	2.185	2.39	2.608	2.369	2.815	3.067	
	MP	2.436	2.573	2.71	2.489	2.623	2.757	2.544	2.73	2.924	2.718	3.054	3.3	
	FEM	2.467	2.681	2.889	2.503	2.713	2.94	2.566	2.824	3.094	2.713	3.127	3.389	
	F	2.261	2.403	2.558	2.304	2.455	2.617	2.372	2.56	2.757	2.577	3.007	3.35	Foundation 15%
	B	2.507	2.683	2.865	2.556	2.735	2.915	2.618	2.834	3.065	2.768	3.179	3.537	
	J	2.163	2.338	2.523	2.201	2.388	2.579	2.269	2.481	2.701	2.439	2.922	3.324	
	MP	2.557	2.705	2.859	2.606	2.757	2.91	2.665	2.855	3.06	2.834	3.209	3.547	
	FEM	2.528	2.752	2.975	2.563	2.788	3.027	2.634	2.895	3.164	2.789	3.254	3.665	

2. Experimental Design, Materials and Methods

Embankments with five different highs were modeled: 6 m, 12 m, 18 m, 24 m, and 30 m. Each embankment height was varied in different slopes. Three 6-m-high slopes were set at 1:1, 1.5:1, and 2:1, respectively, while 6 slopes for the 12-m embankment high were used, as is showed in Fig. 1. Nine variations in slopes were used for the embankment 18 m high (Fig. 2), four variations for the embankments 24 m high (Table 1) and three for the embankments 30 m high (Table 2). Slopes for all embankment heights were defined previously elsewhere [1].

Additionally, a multifactorial design was employed, where soils in the embankments were varied according to 12 levels (Table 3), where V.1, V.2, and V.3 represent the low, medium, and high parameters, respectively, of the AASHTO classification A-1, A-2, A-3, and A-4 [4, 5]. The foundation soil was divided into three levels, whose physical and mechanical parameters represent foundations with CBR of 3%, 5%, and 15%. A total of 900 simulations were made, for which the dataset can be found at http://dx.doi.org/10.17632/59j9bvsrxt.2.

Ethics Statement

No ethical issues are associated with this work.

Supplementary Material

Supplementary full data associated with this article can be found in the online version at doi:10.17632/59j9bvsrxt.2.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that have or could be perceived to have influenced the work reported in this article.

CRediT Author Statement

Milena Mesa-Lavista: Conceptualization, Data curation, Methodology, Writing – original draft; **José Álvarez-Pérez:** Data curation, Writing – original draft; **Eduardo Tejeda-Piusseaut:** Supervision, Resources, Writing – review & editing; **Francisco Lamas-Fernández:** Supervision, Writing – review & editing.

Acknowledgments

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