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Effects of Mechanics Parameters of Gravel Overburden on Deformation of Concrete Face Rockfill Dam

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Abstract

In this paper, Duncan-Chang E-B model was used to simulate the constitutive relation of gravel overburden, to study the sensitivity of parameters of Duncan-Chang E-B model to the deformation of concrete face rockfill dam, and to explore the influence rules of sensitive parameters on the deformation of concrete face rockfill dam. The results of the study show that among the Duncan-Chang E-B model parameters of gravel overburden, the sensitivity of φ_o, K_b, K, R_f, m are listed in order of largest to smallest impact on the deformation of the dam. The dam displacement and the slab deflection decreased with an increase in φ_o-value, K_b-value, K-value and m-value, and increased with an increase in R_f-value. φ_o-value has a great influence on the horizontal displacement and vertical settlement displacement of the dam, and has relatively little effect on the deflection of the slab. The deflection of the slab, coupled with the horizontal displacement and vertical settlement displacement of the dam are greatly related to K_b-value. K-value has a relatively appreciable impact on the horizontal displacement of the dam, and has a relatively small effect on the vertical settlement displacement of the dam and the deflection of the slab. The horizontal displacement of the dam is greatly influenced by R_f-value, and the vertical settlement displacement of the dam and the deflection of the slab are hardly influenced by R_f-value. m-value has little impact on the displacement of the dam and the deflection of the slab.

Keywords

Gravel Overburden; Mechanics Parameters; Concrete Face Rockfill Dam; Deformation.

1. Introduction

Since the reform and opening up, great progress has been made in economic construction and construction technology in China, and more and more face rockfill dams need to be built on deep overburden [1]. During the construction and water storage of concrete face rockfill dam, the sand and gravel overburden layer will undergo obvious settlement deformation, which is very different from the rock foundation.After obvious settlement and deformation of the foundation, the deformation of the upper dam body and seepage prevention of the panel will also be greatly affected.Sand and gravel overburden is common in dam foundation, Duncan-Zhang E-B model can well simulate the stress-strain relationship of sand and gravel [2]. With other models, parameter acquisition of Duncan-Zhang E-B model is relatively convenient. The three methods of parameter acquisition are: indoor test such as triaxial test; inversion analysis based on actual monitoring operation results; similar engineering analogy based on completed projects [3]. Each of these three methods has its advantages and disadvantages.The results of literature [4-11] show that the change of parameters of the constitutive model has more influence on the calculation results than the model itself.Therefore, it is necessary

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and meaningful to use Duncan-Zhang E-B model parameters to carry out sensitivity analysis of dam body and panel deformation and to analyze the law of influence of sensitive parameters on dam body and panel deformation.

In this paper, the skew-faced rockfill dam is taken as an example to explore the sensitivity of Duncan-Zhang E-B model parameters of sand-gravel overburden to the deformation of dam body and face and the influence rule of sensitivity parameters on the deformation of dam body and face.

2. Sensitivity analysis of mechanical parameters of sand and gravel overburden

2.1 General situation of the project

The inclined-card face rockfill dam is located on the Taka River [13] in Jiulong County, Ganzi Prefecture, Sichuan Province. According to data, the dam crest elevation is 3168.0m, the dam bottom elevation is 3059.8m, the dam crest width is 10.0m, the upstream dam slope is 1:1.4, and the downstream dam slope is 1:1.35. The river bed of dam foundation has 45-100m overburden layer, mainly composed of sand, pebble and gravel.The sectional diagram of the dam body of the inclined panel rockfill dam is shown in Figure. 1.

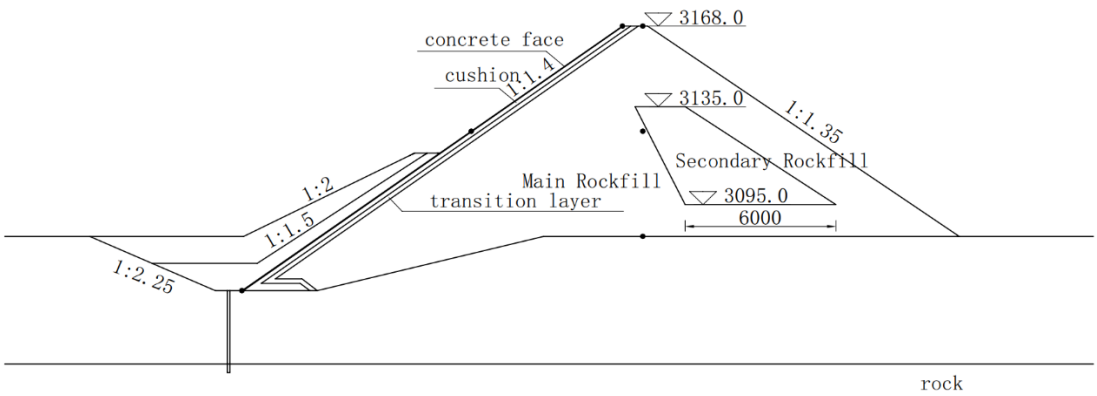

Figure 1. Section sketch of inclined panel rockfill dam (elevation unit: m)

2.2 Material parameters

Concrete panels, concrete cut-off walls and toe slabs are considered as linear elastic materials with a density of $\rho_d = 2400\text{kg/m}^3$, modulus of elasticity $E = 2.0 \times 10^4\text{MPa}$. See Table. 1 for model parameters of dam body and sand-gravel overburden.

Table 1. Calculation parameters of Duncan-Zhang E-B model for different zones of skew-faced rockfill dam

Material	K	n	R_f	C/(kPa)	φ_0 / (°)	$\Delta\varphi_0$ / (°)	K_b	m	K_{ur}	ρ / (g · cm^{-3})
cushion	1150	0.23	0.78	20	41.9	3.1	410	0.26	2200	2.13
transition layer	1560	0.24	0.82	15	45.3	5.0	580	0.16	2700	2.14
Main Rockfill	1040	0.30	0.81	30	48.8	8.7	495	0.30	2000	2.04
Secondary Rockfill	980	0.32	0.84	30	47.8	7.5	460	0.32	1950	2.01
Overburden	950	0.36	0.78	25	43.5	5.0	405	0.30	1900	2.11

2.3 Orthogonal experimental design

2.3.1 Test index

Based on the principle of selecting test indexes in parameter sensitivity analysis, it is considered that the deformation of dam body and face plate on sand-gravel overburden is related not only to self-weight of dam body and water load, but also to self-settlement of sand-gravel overburden [14]. Therefore, this paper selects the maximum vertical deformation of the dam *V*, the maximum

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horizontal deformation upstream H_u and downstream H_d, and the maximum deflection of the face slab ω as the main test indexes.

2.3.2 Test factors and factor levels

There are 10 calculation parameters in Duncan-Zhang E-B model, of which the bulk weight of material gamma γ is easy to measure and the value of parameter $\Delta\varphi$ itself is relatively small [4]. Therefore, the sensitivity analysis is not considered for the parameters gamma γ and $\Delta\varphi$. It is noteworthy that the loading process of the face rockfill dam is simulated during the completion period and the parameter K_{ur} is generally considered $K_{ur} = (1.2\sim3.0)K$ [15], so unloading parameter K_{ur} is not considered.

Therefore, based on the laboratory test parameters and taking the foundation of sand-gravel overburden as the main research object, $K, n, R_f, c, \varphi_0, K_b, m$ in the basic structure model of sand-gravel overburden dam are selected in this paper.And up and down by 20% [12, 16-17] as 3 test levels.The level of factors in orthogonal test is shown in Table 2. The level of factors in orthogonal test is shown in Table. 2.

Table 2. Level values of orthogonal test factors

Factor level	K	n	R_f	C/(kPa)	φ_0 / (°	K_b	m
1	760	0.288	0.624	20	34.8	324	0.255
2	950	0.360	0.780	25	43.5	405	0.300
3	1140	0.432	0.936	30	52.2	486	0.345

2.3.3 Design scheme of orthogonal test

Based on the principles of mathematical statistics and orthogonality, orthogonal test is an effective method which can not only greatly reduce the number of tests, but also achieve the purpose of comprehensive experimental analysis [17]. In this paper, non-standard orthogonal table $L_{18}(2\times3^7)$ (i.e. the first row of orthogonal test table is empty) is selected, and the horizontal value of each factor is filled into the orthogonal table, i.e. the orthogonal test design scheme of sand and gravel overburden foundation material is obtained, totally 18 groups, see Table 3. The experimental indexes V, H_u, H_d, ω, the results are listed in Table 3.

Table 3. Design scheme and calculation results of orthogonal test

Program-mme	Blank Line	K	n	R_f	C /(kPa)	φ_0 / (°)	K_b	m	Maximum Deformation of Dam Body			Maximum panel Deformation value
									V(m)	H_u(m)	H_d(m)	ω(m)
1	1	760	0.288	0.624	20	34.8	324	0.24	-1.793	-0.717	0.374	0.367
2	1	760	0.360	0.780	25	43.5	405	0.30	-1.331	-0.473	0.267	0.292
3	1	760	0.432	0.936	30	52.2	486	0.36	-1.047	-0.340	0.197	0.221
4	1	950	0.288	0.624	25	43.5	486	0.36	-1.109	-0.382	0.219	0.231
5	1	950	0.360	0.780	30	52.2	324	0.24	-1.421	-0.332	0.181	0.308
6	1	950	0.432	0.936	20	34.8	405	0.30	-1.570	-0.694	0.380	0.359
7	1	1140	0.288	0.780	20	52.2	405	0.36	-1.135	-0.303	0.171	0.244
8	1	1140	0.360	0.936	25	34.8	486	0.24	-1.503	-0.646	0.348	0.314
9	1	1140	0.432	0.624	30	43.5	324	0.30	-1.394	-0.357	0.197	0.308
10	2	760	0.288	0.936	30	43.5	405	0.24	-1.499	-0.550	0.326	0.315
11	2	760	0.360	0.624	20	52.2	486	0.30	-1.053	-0.309	0.174	0.225
12	2	760	0.432	0.780	25	34.8	324	0.36	-1.643	-0.702	0.385	0.339
13	2	950	0.288	0.780	30	34.8	486	0.30	-1.412	-0.630	0.347	0.297
14	2	950	0.360	0.936	20	43.5	324	0.36	-1.482	-0.517	0.298	0.312
15	2	950	0.432	0.624	25	52.2	405	0.24	-1.134	-0.255	0.132	0.252
16	2	1140	0.288	0.936	25	52.2	324	0.30	-1.408	-0.346	0.208	0.311
17	2	1140	0.360	0.624	30	34.8	405	0.36	-1.326	-0.505	0.268	0.283
18	2	1140	0.432	0.780	20	43.5	486	0.24	-1.160	-0.351	0.189	0.248

Note: Negative vertical deformation of dam body represents downward settlement, negative horizontal deformation of dam body represents upstream deformation and positive horizontal deformation of dam body represents downstream deformation.

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2.4 Calculation results and analysis

Mathematical analysis of each test index is carried out by using range analysis method, and the range R of each test factor is obtained.J. The analysis results are shown in Table 4-Table 7.Table 4 shows that the sensitivity of each test factor to the maximum vertical deformation V is in the order of large to small: $\varphi_o, K_{b,} m, R_{f,} K, n, c$.

Table 4. Range analysis results of influencing factors for maximum vertical deformation V

Factor	K	n	R_f	C/(kPa)	φ_0 / (°)	K_b	m
K_1	-0.038	-0.036	0.055	-0.009	-0.185	-0.167	-0.062
K_2	0.002	0.004	0.006	0.002	0.027	0.024	-0.005
K_3	0.036	0.032	-0.062	0.007	0.157	0.143	0.066
R_j	0.073	0.068	0.117	0.016	0.342	0.310	0.128
susceptibility	$\varphi_o > K_b > m > R_f > K > n > c$						

Table 5 shows that each test factor has a maximum upstream horizontal deformation H_u. The sensitivity of u ranges from large to small: $\varphi_o, K, R_f, K_{b,} n, c, m$.

Table 5. Range analysis results of influencing factors for maximum horizontal deformation upstream H_u

Factor	K	n	R_f	C/(kPa)	φ_0 / (°)	K_b	m
K_1	-0.048	-0.021	0.046	-0.015	-0.182	-0.028	-0.008
K_2	-0.001	0.004	0.002	0.000	0.029	0.004	-0.001
K_3	0.049	0.017	-0.048	0.015	0.153	0.024	0.009
R_j	0.097	0.038	0.095	0.030	0.335	0.052	0.017
susceptibility	$\varphi_o > K > R_f > K_b > n > c > m$						

As shown in Table 6, each test factor influences the maximum horizontal deformation downstream Hd Sensitivity from large to small :$\varphi_o, R_f, K, K_b, n, c, m$.

Table 6. Maximum Horizontal Deformation H_d downstreamResult of Range Analysis of Influencing Factors

Factor	K	n	R_f	C/(kPa)	φ_0 / (°)	K_b	m
K_1	0.028	0.015	-0.032	0.005	0.091	0.015	0.000
K_2	0.001	-0.003	-0.002	0.001	-0.010	-0.002	0.003
K_3	-0.029	-0.013	0.034	-0.006	-0.082	-0.013	-0.003
R_j	0.057	0.028	0.066	0.012	0.173	0.028	0.006
susceptibility	$\varphi_o > R_f > K > K_b > n > c > m$						

Table 7 shows that the sensitivity of each test factor to the maximum deflection ω of the panel is in the order of large to small: $K_b, \varphi_o, m, R_{f,} K, n, c$.

Table 7. Result of range analysis for influencing factors of maximum deflection ω of panel

Factor	K	n	R_f	C/(kPa)	φ_0 / (°)	K_b	m
K_1	0.003	0.004	-0.013	0.002	0.036	0.034	0.010
K_2	0.003	-0.001	-0.003	-0.001	-0.006	0.000	0.008
K_3	-0.006	-0.002	0.015	-0.002	-0.030	-0.034	-0.019
R_j	0.009	0.006	0.028	0.004	0.066	0.068	0.029
susceptibility	$K_b > \varphi_o > m > R_f > K > n > c$						

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According to the principle that the larger the range value is, the more sensitive the factors are to the indexes. According to the range analysis results in Table 4-7, the parameters $\varphi_o, K_{b,} m, R_f$ of Duncan Chang E-B model for sand gravel overburden have the greatest influence on the vertical deformation of the dam, and the parameters φ_o are the most sensitive to the test indexes, followed by the parameters K_b. The parameters φ_o, K, R_f have the greatest influence on the upstream horizontal deformation of the dam, and the parameters φ_o are the most sensitive to the test indexes, followed by the parameters K. Compared with the range value of the index V, H_u, the range value of the index H_d, ω is smaller, which indicates that the change of Duncan Chang E-B model parameters of sand gravel overburden has less influence on the downstream horizontal deformation and panel deflection. Relatively speaking, the parameters φ_o have the greatest influence on the downstream horizontal deformation, and the parameters φ_o, K_b have the greatest influence on the panel deflection.

3. Influence of sensitive parameters of sand gravel overburden on dam deformation

From the sensitivity analysis of the above parameters of Duncan Chang E-B model for sand gravel overburden, it can be known that the parameters $\varphi_o, K, R_{f,} K_b, m$ are more sensitive to the deformation of concrete faced rockfill dam body and face slab, that is, the small changes of these parameters have a greater impact on the numerical calculation results of dam body deformation. Therefore, it is necessary to analyze the influence of sensitive parameters of Duncan Chang E-B model on dam deformation.

3.1 Internal friction angle φ_o influence on dam deformation

The calculation results of dam deformation affected by internal friction angle φ_o are shown in Table. 8.

Table 8. Influence of internal friction angle on dam deformation

Parameter change rate (%)	Vertical deformation (m)	Rate of change (%)	Horizontal deformation				Panel deflection (m)	Rate of change (%)
			Deformation upstream (m)	Rate of change (%)	Deformation downstream (m)	Rate of change (%)		
$-30\varphi_o$	-1.726	33.282	-0.884	105.390	0.427	79.219	0.508	7.009
$-15\varphi_o$	-1.451	12.046	-0.584	35.711	0.312	30.856	0.484	1.915
φ_o	-1.295	0	-0.430	0	0.238	0	0.475	0
$15\varphi_o$	-1.192	-7.954	-0.332	-22.793	0.186	-22.040	0.471	-0.821
$30\varphi_o$	-1.116	-13.822	-0.264	-38.615	0.145	-39.211	0.469	-1.263

It can be seen from Table. 8 that when the internal friction angle φ_o increases, the deformation of the dam body and the deflection of the face plate gradually decrease. The change of internal friction angle φ_o has a great influence on the horizontal deformation of the dam, a certain influence on the vertical deformation of the dam, and a very small influence on the deflection of the face slab.

3.2 Influence of elastic modulus coefficient K on dam deformation

The calculation results of the influence of elastic modulus coefficient K on dam deformation are shown in Table. 9.

Table 9. Influence of elastic modulus coefficient K on dam deformation

Parameter change rate (%)	Vertical deformation (m)	Rate of change (%)	Horizontal deformation				Panel deflection (m)	Rate of change (%)
			Deformation upstream (m)	Rate of change (%)	Deformation downstream (m)	Rate of change (%)		
$-30K$	-1.359	4.942	-0.507	17.970	0.2900	21.951	0.2782	3.075
$-15K$	-1.319	1.853	-0.460	7.076	0.2586	8.747	0.2731	1.186
K	-1.295	0	-0.430	0	0.2378	0	0.2699	0
$15K$	-1.278	-1.313	-0.407	-5.168	0.2236	-5.971	0.2681	-0.667
$30K$	-1.266	-2.239	-0.391	-9.101	0.2128	-10.513	0.2667	-1.186

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It can be seen from Table. 9 that the deformation of the dam body and the deflection of the face slab gradually decrease with the increase of the elastic modulus coefficient K. The change of elastic modulus coefficient K has a great influence on the horizontal deformation of the dam, and the influence law and degree on the horizontal deformation of the upstream and downstream of the dam are basically the same; the influence on the vertical deformation of the dam and the deflection of the face slab is very small.

3.3 Influence of failure ratio R_f on dam deformation

The calculation results of dam deformation affected by failure ratio R_f are shown in Table. 10.

Table 10. Influence of failure ratio R_f on dam deformation

Parameter change rate (%)	Vertical deformation (m)	Rate of change (%)	Horizontal deformation				Panel deflection (m)	Rate of change (%)
			Deformation upstream (m)	Rate of change (%)	Deformation downstream (m)	Rate of change (%)		
$-30R_f$	-1.200	-7.336	-0.3435	-20.042	0.1874	-21.194	0.2563	-5.039
$-15R_f$	-1.249	-3.552	-0.3907	-9.055	0.2128	-10.513	0.2633	-2.445
R_f	-1.295	0	-0.4296	0	0.2378	0	0.2699	0
$15R_f$	-1.341	3.552	-0.4677	8.869	0.2623	10.303	0.2759	2.223
$30R_f$	-1.461	12.819	-0.5958	38.687	0.3190	34.146	0.2843	5.335

It can be seen from Table 10 that the deformation of the dam body and the deflection of the face slab gradually increase with the increase of the failure ratio R_f. The influence of the change of failure ratio R_f on the horizontal deformation of upstream dam is basically consistent with that on the horizontal deformation of downstream dam, and the influence on the vertical deformation of dam and the deflection of face slab is relatively small.

3.4 Influence of initial bulk modulus coefficient K_b on dam deformation

The calculation results of the influence of initial bulk modulus coefficient K_b on dam deformation are shown in Table. 11.

Table 11. Influence of initial bulk modulus coefficient K_b on dam deformation

Parameter change rate (%)	Vertical deformation (m)	Rate of change (%)	Horizontal deformation				Panel deflection (m)	Rate of change (%)
			Deformation upstream (m)	Rate of change (%)	Deformation downstream (m)	Rate of change (%)		
$-30K_b$	-1.670	28.958	-0.5184	20.698	0.2778	16.772	0.3625	25.693
$-15K_b$	-1.433	10.656	-0.4647	8.196	0.2537	6.641	0.3181	10.298
K_b	-1.295	0	-0.4295	0	0.2379	0	0.2884	0
$15K_b$	-1.194	-7.799	-0.4048	-5.751	0.2273	-4.456	0.2675	-7.247
$30K_b$	-1.116	-13.822	-0.3874	-9.802	0.2200	-7.524	0.2520	-12.621

It can be seen from Table 11 that the deformation of the dam body and the deflection of the face slab gradually decrease with the increase of the initial bulk modulus coefficient K_b. The change of initial bulk modulus coefficient K_b has great influence on the horizontal deformation, vertical deformation and face slab deflection of the dam, and the influence degree is in the order of vertical deformation, face slab deflection, upstream horizontal deformation and downstream horizontal deformation.

3.5 Influence of bulk modulus index m on dam deformation.

The calculation results of dam deformation affected by bulk modulus index m are shown in Table. 12.

It can be seen from Table 12 that the vertical deformation of the dam and the deflection of the face slab gradually decrease with the increase of the bulk modulus index m, but the change of the bulk

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modulus index m has little effect on the vertical deformation of the dam and the deflection of the face slab. The influence of bulk modulus index m on horizontal deformation of dam is very small.

Table 12. Influence of bulk modulus index m on dam deformation

Parameter change rate (%)	Vertical deformation (m)	Rate of change (%)	Horizontal deformation				Panel deflection (m)	Rate of change (%)
			Deformation upstream (m)	Rate of change (%)	Deformation downstream (m)	Rate of change (%)		
$-30m$	-1.3710	6.362	-0.4134	0.24	0.2353	-1.424	0.2786	10.162
$-15m$	-1.3290	3.103	-0.4122	-0.05	0.2366	-0.880	0.2655	4.982
m	-1.2890	0	-0.4124	0	0.2387	0	0.2529	0
$15m$	-1.2520	-2.870	-0.4126	0.05	0.2410	0.964	0.2408	-4.784
$30m$	-1.2150	-5.741	-0.4126	0.05	0.2431	1.843	0.2299	-9.095

4. Conclusion

(1) The sensitivity of parameters in Duncan Chang E-B model of sand gravel overburden to dam deformation is in descending order: $\varphi_{o,}K_b, K, R_{f,}m$.

(2) With the increase of internal friction angle φ_o, the deformation of dam body and the deflection of face slab decrease gradually. The change of internal friction angle φ_o has a great influence on the horizontal deformation of the dam, a certain influence on the vertical deformation of the dam, and a very small influence on the deflection of the face slab.

(3) With the increase of initial bulk modulus coefficient K_b, the deformation of the dam body and the deflection of the face slab gradually decrease. The change of initial bulk modulus coefficient K_b has great influence on the horizontal deformation, vertical deformation and face slab deflection of the dam, and the influence degree is in the order of vertical deformation, face slab deflection, upstream horizontal deformation and downstream horizontal deformation.

(4) The deformation of the dam and the deflection of the face slab decrease with the increase of the elastic modulus coefficient K. The change of elastic modulus coefficient K has a great influence on the horizontal deformation of the dam, but has little influence on the vertical deformation of the dam and the deflection of the face slab.

(5) The deformation of the dam and the deflection of the face slab increase with the increase of the failure ratio R_f. The change of failure ratio R_f has great influence on the horizontal deformation of the dam, but little influence on the vertical deformation of the dam and the deflection of the face slab.

(6) With the increase of bulk modulus index m, the vertical deformation of the dam and the deflection of the face slab gradually decrease, but the change of bulk modulus index m has little effect on the vertical deformation of the dam and the deflection of the face slab, and has little effect on the horizontal deformation of the dam.

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