Impact of Daily Cyclic Water Level Fluctuations on Concrete-Face Rockfill Dams in Pumped-Storage Power Stations

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ABSTRACT

In the case of increasing energy constraints, the construction of Pumped storage power plants (PSPs) can be used to adjustpeaks and valleys and make better use of clean energy. The concrete-face rockfill dam (CFRD) has become a PSP preferred dam type. However, CFRDs in PSP face more complex working conditions. Understanding the working conditions of CFRDs in PSP is essential to ensure the proper and safe construction and operation of dams. In this paper, the history of CFRDs in PSP with actual construction measurements as well as monitoring information is collected statistically, mainly based on engineering literature. The correlation between deformation, seepage and several different influencing factors such as dam height, foundation conditions, and valley shape was investigated in order to recognize the characteristics of the dam in this case, with the expectation of providing engineering analogies and references for future corresponding projects. It is found that the CFRD in PSP basically conforms to the general law of ordinary CFRD, while there is greater deformation in crest settlement deformation and face slab deflections due to the large changes in water level fluctuation in PSPs, terrain conditions and design specification, but for internal settlement deformation and leakeage rate is much smaller. Total reservoir capacity, on the other hand, is adversely affected by dam deformation and face slab deflections on rock foundation, while the opposite is true for alluvium foundation.

Keywords: Psps; Cfrds; Deformation; Seepage; Water Level Flucation; Statistical Analysis

INTRODUCTION

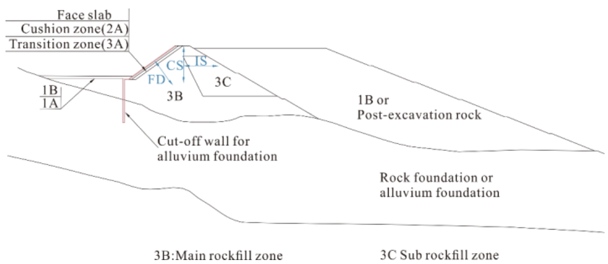
The construction of pumped storage power plants (PSPs) has been vigorously developed in recent years due to energy constraints and green environmental considerations [1-3]. A PSP is a special type of hydroelectric power plant that uses electrical energy to pump water to an upstream reservoir when the energy demand is low and releases the water back to a downstream reservoir to generate electricity when the energy demand is high [4,5]. This form of coordination of the time imbalance between power output and demand can also be used to regulate the unstable power generated by wind and solar power to make up for the peak, achieve better grid-connectivity, and improve the utilization rate of green clean energy.The PSPs have been built for more than 130 years in the world, and there is more installed capacity in the US, Japan, Germany [4].Since the 1960s, China began the construction of PSPs, in recent years, China's pumped storage construction has accelerated significantly, and the installed capacity of China's PSPs has jumped to the first in the world[1].

In the early days of the PSPs' construction, most of the upper and lower reservoir dam types were earth-rock dams. With the development of gravity dams and CFRDs, CFRDs have now become the preferred dam type for building pumped storage power plants.However, PSPs face more complex conditions, for example, in order to increase the capacity of the reservoir, the dam axis is always the fold line or curve which is more convex to the downstream surface, when the axis is not a straight line, the inflection point is prone to stress concentration[19-22]; dam site in the southwest region has more deep alluvium (sand and gravel) foundation, the dam deformation settlement has a greater impact[15-18]; The water level fluctuates frequently,the water level fluctuation between storage and power generation in PSPs is mostly experienced from low to high water level and then from high to low water level in a cycle of 24h or 12h[35-37];and under high cold and altitude climate,the face slab is not only subject to the static water load, ice load, alternating water loads, but also adversely affected by all frost swelling of the rock pile; all or most of the water on the reservoir is pumped up from the lower reservoir by comsuming electricity, while the leakage of the resvoir water is the loss of electricity,therefore,PSPs have higher requirements for leakage[40].

However, the design and construction of PSPs are still largely dependent on engineering experience, and it is necessary to evaluate the engineering conditions by using relevant engineering monitoring data that have been built.But few existing studies have addressed the characterization of CFRDs in PSPs, so it is necessary to conduct statistical analysis for new problems to provide theoretical guidance for the problems that will be faced in engineering. This paper collects and organizes the monitoring data of CFRDs in 32 constructed PSPs, and analyzes the dam deformation, face slab deflections and seapage flow from the perspective of mathematical analysis, while considering the influence of foundation, valley and seepage shape on dam operation.

2. Engineering Practices And Monitoring Data

A. Engineering practices



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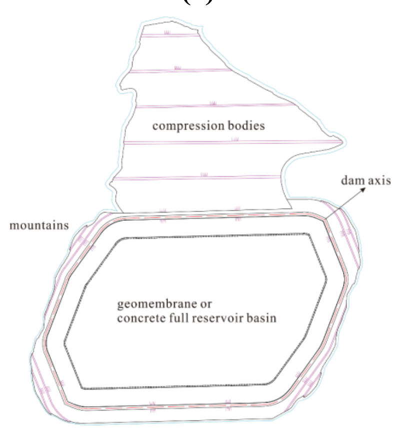

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Fig. 1.CFRDs in PSPs (a) zoning and (b) layout diagram

Modern CFRDs are usually divided into eight zones: face slab, cushion zone (2A), transition zone (3A), main rockfill zone (3B), sub rockfill zone (3C) and cut-off wall [6].The same is true for CFRDs in PSPs, but the zone of the dam, especially the upper reservoir dam, has its own uniqueness [7].Fig. 1. shows a zoning and layout diagram of the upper reservoir dam of a PSP, as can be seendams are mostly constructed in the basin, on excavated foundations, with the back of the rock for filling construction. Therefore, there are often mountains or compression bodies on the downstream side [8].Due to the constraints by terrain condition, it is mostly a low dam, the dam height is not too high, the dam axis is often folded or curved arrangement, the internal can be impermeable with the geomembrane or concrete full reservoir basin to achieve better seepage control effect.

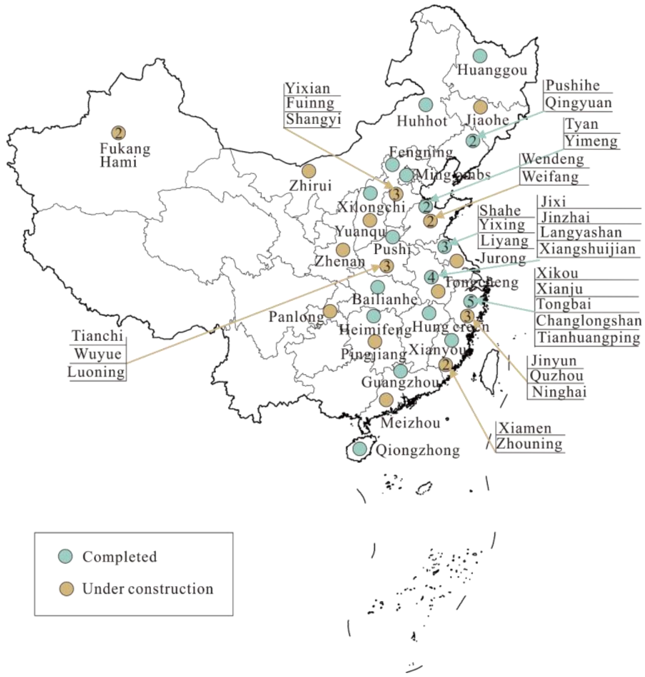


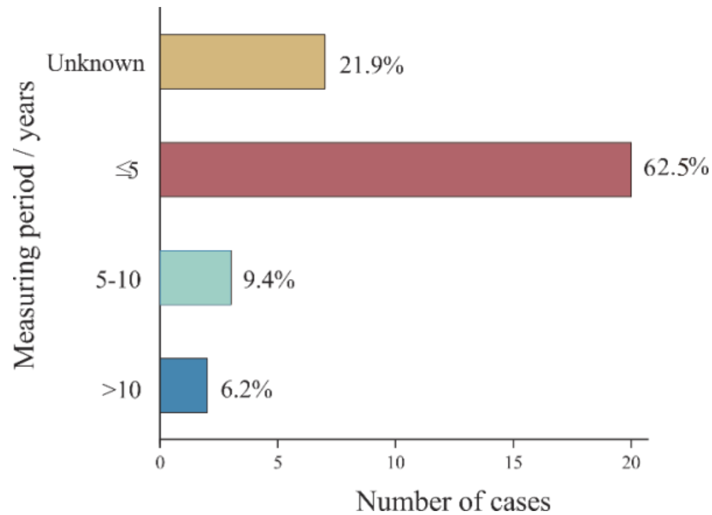
Fig. 2. Distribution of the PSPscompleted and under construction in China (by 2020)

Fig. 2. shows the space distribution of pumped storage power plants that have been built and are under construction in China as of 2020. As can be seen from the figure, China's completed pumped storage power plants are mainly distributed in the eastern region that is rich in hydropower resources, and the number of plants in the northeast is also relatively small, although the number of pumped storage power plants under construction in the central part of the country has increased to a certain extent, but compared to the eastern part of the country, the installed capacity in the central and western parts of China is still relatively little or no. The more complex topography and climatic conditions of central and western China and the degree of demand for power resources are the main factors influencing the construction of pumped storage power plants, and given that pumped storage power plants are characterized by regulating the temporal distribution of power resources, there is a greater need for them in the eastern region, where the demand for power is high [1-4].

B. Engineering monitoring data

This study collected engineering monitoring data from 32 CFRDs in PSPs for dam operational condition assessment. Table 1 shows the engineering construction and operation period monitoring data of 32 PSPs in China since the first PSP was built in 1968.The dam (U) in the table refers to the upper reservoir in a PSP, and (L) is the lower reservoir in a PSP. The 13 CFRDs (NO.1-NO.13) in the table were built on rocky foundation, and the 15 CFRDs (NO.14-NO.28) were completely or partially built on alluvial foundation. The table contains dam parameters such as dam height, crest length, total storage, valley shape factor, single-water water level fluctuation value, etc., as well as monitoring data such as dam deformations and seepage parameter flow.Fig.2. reflects the percentage of different dam height, monitoring period (from construction completion to monitoring time), total storge and the single-water water level fluctuation value.

The figure shows that the most of the projects have been tested for less than 5 years, and some of them have been built for a shorter period of time and lack monitoring data, the measurement period is in the range of 1-16.5 years, but there is also a lack of long-term monitoring of engineering cases, and the dams in China are built in a relatively short period of time. The dam heights are mainly in the range of 30-120m. Obviously, CFRDs in PSPs are mostly medium to high dams 40m-100m. The water level fluctuation is larger compared to normal CFRDs, which is generally between 6 and 45m, and more than half of the CFRDs in PSPs have a reservouir level variation of 20m or more in the case of not high dams.Excluding the projects for which total capacity data were not available and one below 100*104m³ (Xikou L), most of the PSPs' total storge is between 100 and 5000*104m³, which are classified as small reservoirs. In this paper, The valley shape factor(SF) describing the shape of the valley is the ratio of the length of the crest length (CL) to the dam height(H), and it is narrow valleys when SF < 3.1, otherwise it is a wide valley. An important factor affecting the safe operation of CFRDs is dam deformation.Three variability parameters are used to describe the deformation of CFRDs: Crest settlement (CS), internal settlement (IS), and face slab deflections (FD), the deformation parameters of all dams are expressed by dividing the deformation by the height of the dam, and the normalized parameters are used to analyze different dams.The analysis method is based on the discussion of deformation and seepage in CFRDs in Wen Lifeng et al [12-14]. Because the amount of seepage plays a decisive role in the effectiveness of PSPs, taking into account the daily permeation standards of PSPs at home and abroad, the daily seepage is generally controlled within 0.02%~0.05% of the total storge(TS)[40, 41].



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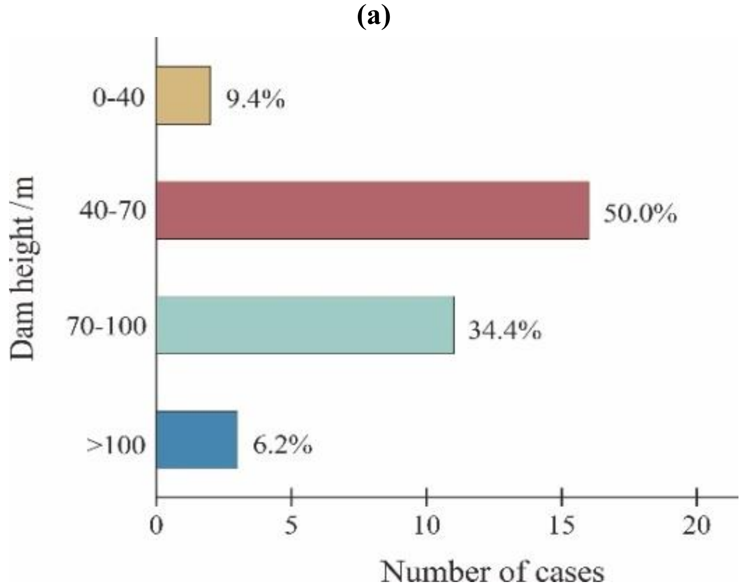

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Table 1. Case history data and behaviour measurements of 32 CFRDs in PSPs

NO.	Dam	Address	Year	H	CL	TS	Δ	Foundation	Rockfill source	SF	IS		CS		FD		L	PS	MP
				m	m	104 m	m			CL/H	m	%H	m	%H	m	%H	L/s	‰	year
1	Xikou(U)	Zhejiang	1998	37	154	103	15.9	R	conglomerate	4.2	0.01	0.02	0.17	0.45	0.14	0.38	7.7	0.75	3.5
2	Xikou(L)	Zhejiang	1998	46.5	—	68	14.5	R	Sandstone	—	0.01	0.02	0.16	0.34	0.13	0.29	—	—	3.6
3	Shahe(U)	Jiangsu	2002	47	529	262	16	R	Tuff	11.2	—	—	—	—	—	—	4.7	0.18	—
4	Qiongzhong(L)	Hainan	2016	54	370	892	14	R	Sandstone	6.9	—	—	—	—	—	—	—	—	—
5	Langyashan(U)	Anhui	2007	64	655	1804	16.9	R	Limestone	10.2	—	—	0.18	0.29	—	—	0.2	0.001	0.5
6	Heimifeng(U)	Hunan	2010	64.5	—	—	23.5	R	Granite	—	—	—	0.16	0.25	—	—	47	—	7.3
7	Guangzhou(U)	Guangdong	1992	68	319	2400	19.8	R	Granite	4.7	0.02	0.03	0.29	0.43	0.20	0.30	1	0.004	10.5
8	Tongbai(L)	Zhejiang	2006	68.3	434	1284	31.2	R	Tuff	6.4	—	—	0.20	0.29	—	—	3	0.02	2.6
9	Yixing(U)	Jiangsu	2008	75.2	495	531	42.9	R	Sandstone	6.6	0.60	0.79	0.13	0.17	0.44	0.58	2	0.04	1.8
10	Xiangshuijian(U)	Anhui	2013	87	520	1776	22	R	Granite	6.0	0.22	0.26	0.61	0.70	0.63	0.72	12.4	0.07	3.1

11	Tyan(U)	Shandong	2007	99.8	540	1168	24	R	Granite	5.4	0.07	0.07	0.67	0.67	0.59	0.59	16.3	0.14	2.5
12	Jixi(U)	Anhui	2020	117.7	336	—	40	R	Sandstone	2.9	0.09	0.07	0.23	0.19	0.23	0.20	—	—	2.5
13	Fengning(U)	Hebei	2021	120.3	556	4814	45	R	Rhyolite	4.6	—	—	0.87	0.72	—	—	—	—	3.6
14	Hung creen(U1)	Jiangxi	2016	37.4	312	3077	6	G	Sandstone	8.3	0.01	0.02	0.01	0.02	—	—	15	0.05	3.8
15	Xilongchi(U)	Shanxi	2008	50.9	401	469	25.5	WR	Limestone	7.9	—	—	—	—	—	—	3.4	0.07	—
16	Hung creen (U2)	Jiangxi	2016	57.7	368	3077	6	G	quartzite	6.4	0.01	0.02	0.01	0.02	—	—	12.2	0.04	3.8
17	Huhhot(U)	Inner Mongolia	2015	62.5	1266	—	37	—	Granite	20.3	0.04	0.07	0.86	1.37	0.09	0.15	—	—	1.5
18	Bailianhe(U)	Hubei	2009	62.5	300	2496	17	G	Granite	4.8	0.29	0.46	0.33	0.53	0.44	0.70	1.6	0.01	4
19	Tianhuang ping(U)	Zhejiang	1998	72	503	919	28.4	WR	Tuff	7.0	0.05	0.07	0.64	0.89	0.59	0.82	2	0.02	—
20	Xianyou(U)	Fujian	2015	73.6	340	1979	26	G	Tuff	4.6	0.01	0.02	0.35	0.48	0.29	0.40	48.3	0.24	3.5
21	Xianyou(L)	Fujian	2015	73.9	263	1675	28	G	Granite	3.6	0.01	0.01	0.03	0.04	0.03	0.04	11.6	0.07	3.5
22	Ming ombs(U)	Beijing	1997	75	550	445	35	G	Andesite	7.3	0.83	1.11	0.91	1.21	1.22	1.63	5.6	0.13	2.5
23	Jinzhai(U)	Anhui	202	76	531	—	24	—	Gneiss	7.0	—	—	—	—	—	—	—	—	—

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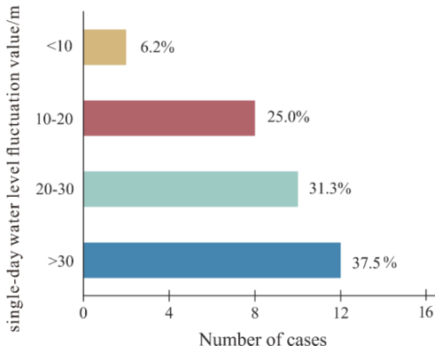
24	Pushihe(U)	Liaoning	2012	78.5	714	1135	32	G	Tuff	9.1	0.33	0.42	0.37	0.48	0.12	0.15	50	—	2
25	Yimeng(U)	Shandong	2022	78.5	—	1026	30	—	Diorite	—	—	—	0.28	0.36	—	—	—	—	2.5
26	Heimifeng(L)	Hunan	2010	79.5	376	862	38.7	G	Granite	4.7	0.26	0.32	0.22	0.27	0.33	0.41	68.6	0.80	7.3
27	Huanggou(U)	Heilongjiang	2022	80	744	1161	12.6	—	Granite	9.3	—	—	—	—	—	—	—	—	—
28	Xianju(U)	Zhejiang	2015	88.2	264	1294	34	G	Tuff	3.0	—	—	0.39	0.44	—	—	16.7	0.13	5
29	Tianhuang ping(L)	Zhejiang	2000	92	225	860	20	G	Tuff	2.4	—	—	1.16	1.15	—	—	5	0.06	16.5
30	Pushi(U)	Henan	2008	96	600	776	25	G	Marlite	6..3	—	—	1.03	1.08	—	—	1.5	0.02	1.5
31	Xilongchi(L)	Shanxi	2008	97	537	432	40	WR	Limestone	5.5	—	—	—	—	—	—	28.6	0.66	—
32	Liyang(U)	Jiangsu	2020	165	1113	1423	37	G	Sandstone	6.7	—	—	0.53	0.32	—	—	13	0.09	1.8

Note:H, dam height; CL, crest length; R, rock foundation; G, alluvium (sand and gravel) foundation; SF, valley shape factor;IS, maximum internal settlement at the end of construction; CS, maximum crest settlement; FD, maximum post-construction face slab deflection;L, leakage after reservoir filling; PS, Permeation standards;MP, measuring period.



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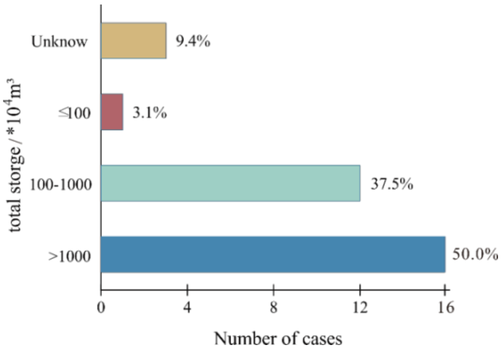

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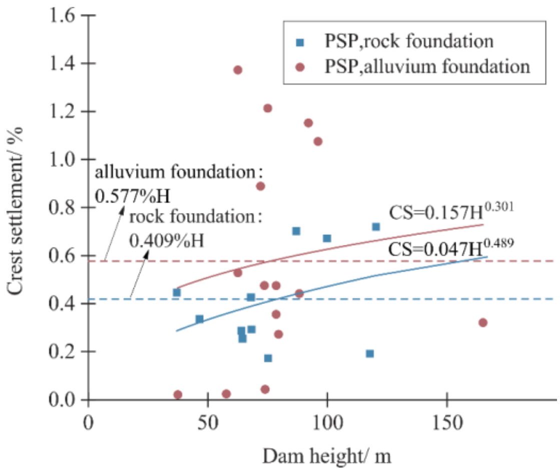
Fig. 3. Data Analysis of: (a) measuring period; (b) dam height; (c) single-day water level fluctuation value and (d) total storge

The Permeation standards (PS), i.e., the ratio of leakeage rate L to total storge (TS), is used as a parameter to evaluate the seepage control effect of the dam.And the single-day water level fluctuation value (Δ) is used to study the periodic frequent water level changes, and the difference between the normal water level and the dead water level is used if there is no specific measured daily water level variation in the project.The database represents CFRDs in PSPs with different foundation types, different valley widths, different reservouir level variations and dam heights ranging from 37 m to 165 m.

3. Statistical Analysis Of Dam Behaviors

A. crest settlement

for the analysis, the data fit is reasonable and the regression coefficient is high. This result in the relationship between dam height and crest settlement under different foundation conditions, the relationship that deformation increases with the increase of dam height is obtained.



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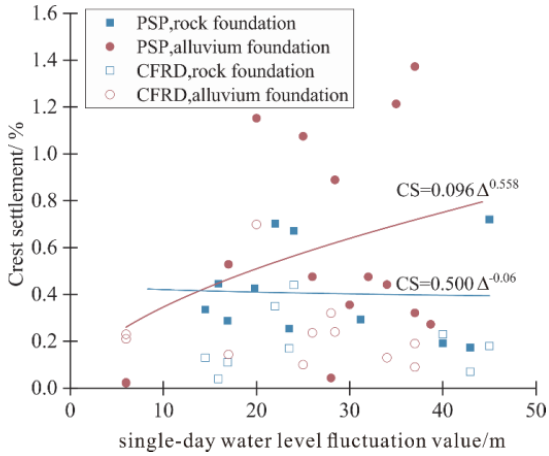

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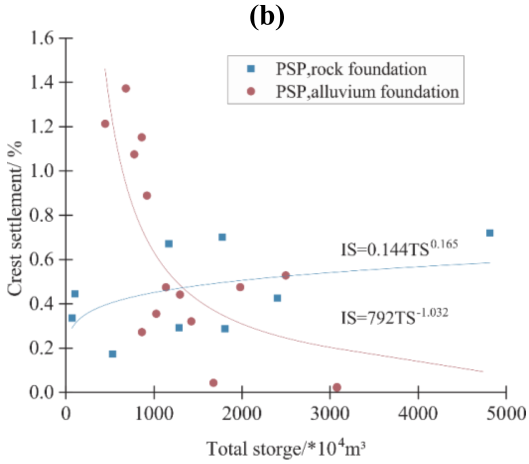

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Fig. 4.crest settlement with (a) dam height, (b) single-day water level fluctuation value and (c) total storge

For ordinary CFRDs with similar dam height and foundation conditions and CFRDs in PSPs with large water level fluctuation, it is obvious that water level fluctuation has an adverse effect on crest settlement, and CFRDs in PSPs are significantly larger, and for CFRDs in the alluvium foundation crest settlement will increase with larger water level fluctuation, while there is no such growth for dams on rock foundations. It can be inferred that the effect of water level fluctuation, i.e., the action of water, will be significantly greater for soil materials with high compressibility than for rock material [32-34]. The total storge has different effects on the crest settlements of CFRDs in PSPs on different foundations, with the larger total storge, the crest settlements on rock foundations are greater, while the opposite is true for dams on alluvium foundation.

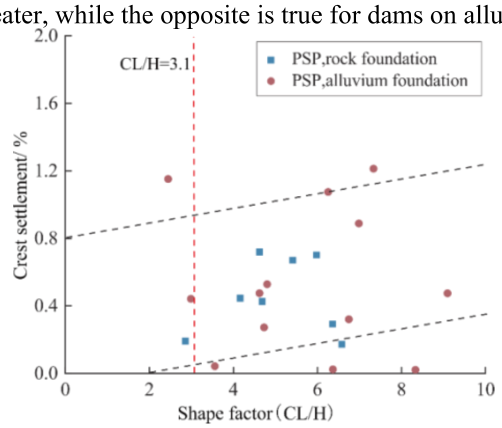
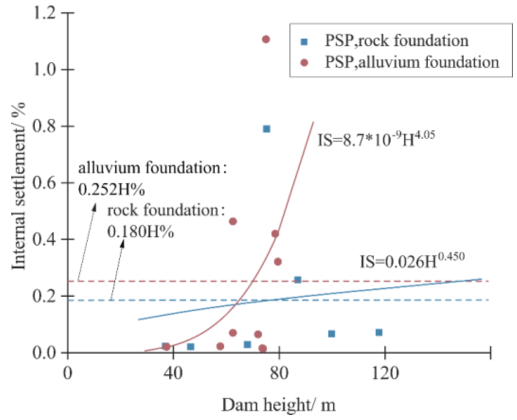


Fig. 5. Crest settlements with respect tothe valley shape factor

Fig. 5. shows the relationship between the valley shape factor and crest settlements.It can be seen that most of the CFRDs in PSPs are located in wide river valleys (SF>3.1), When the dam is in a wide river valley, the Crest settlements is larger and tends to grow asymptotically with the growth of the valley shape factor.Narrow river valleys have a favourable effect on the dam deformation [11], but the engineering data are too homogeneous or limited by the siting of PSPs, which puts most of them in wide river valleys.

B.Internal Settlement



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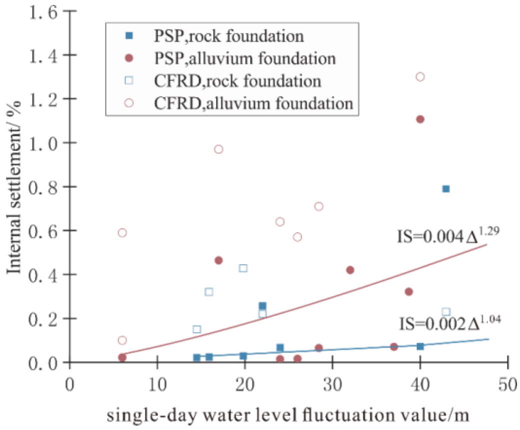

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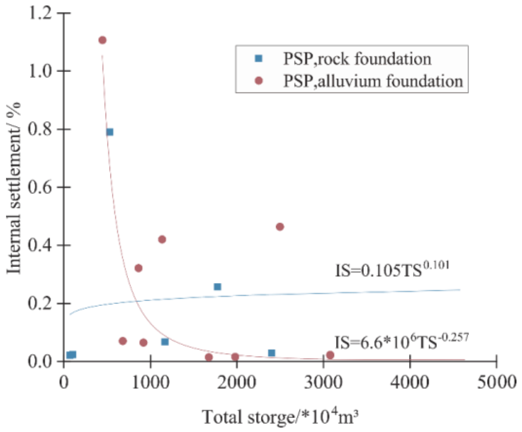


(c)

Fig. 6.CFRD internal settlement with (a) dam height, (b)single-day water level fluctuation value and (c) total storge

Fig. 6. shows the internal settlement of the dam as a function of dam height and water level fluctuation for different dam heights and foundations, and to control the effect of the single variable of water level fluctuation, the internal settlement for similar dam height and foundation conditions in normal CFRDs from the study by Lifeng Wen et al [12-14].The internal settlement during the construction period for all dams on rock foundations was less than 0.8%H, while dams built on alluvium foundation were larger, with all dam internal settlements within 1.2%H. The range of dam internal settlement on rock foundation is 0.02%H to 0.79%H with an average value of 0.18%H,significantly greater than the results of Wen Lifeng et al [12-14]. The averageinternal settlement value of the normal CFRD on rock foundations is 0.15%H and also exceeds its range value of

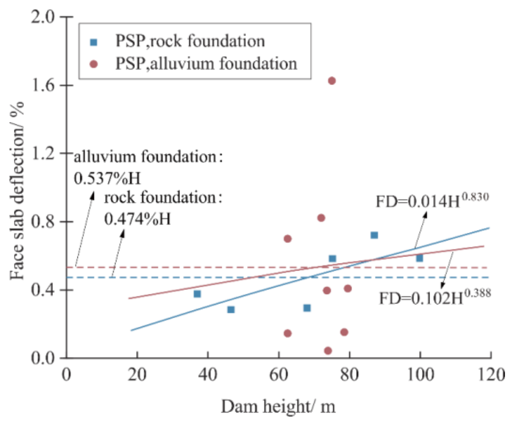
0.25%H, which shows the effect of water level fluctuation on the operation of the CFRDs in PSPs. Influenced by foundation settlement, the range of dam internal settlement on alluvium foundation is 0.02%H to 1.11%H with an average value of 0.252%H,0.072H% greater than the average value of dams on rock foundations,Compared with the results obtained by Wen Lifeng et al [12-14].the average dam internal settlements on alluvium foundation is 0.12H% greater than that on rock foundation, and the internal settlement is less than 0.8% of the total height. The consideration may be that the influence of foundation on internal settlement is weakened by the overall lower dam height in comparison.The same fit analysis of the data revealed thatin the relationship between dam height and internal settlements under differentfoundation conditions, the relationship that deformation increases with the increase of dam height is obtained.However, it may be that the obtained data are too similar in dam height, and the internal settlement varies greatly, and a fast-growing fitted curve is obtained, which may have too much randomness and individual differences and it is not universal.The total storge has different effects on the internal settlements of CFRDs in PSPs on different foundations, with the larger total storge, the internal settlements on rock foundations are greater, while the opposite is true for dams on alluvium foundation. And it can be seen that the relationship between total storge and internal settlements is the same as the effect of total storge on crest settlements.

C. Face Slab Deflections

The face slab deflections mainly come from the uncoordinated deformation of the rigid face slab and the flexible rockfill, and this deformation will also increases greatly under the action of water load, so the face slab deflections during reservoir storage will also produce a large increase, and the maximum deformation occurs in the 1/2 dam height position[42-44].Fig. 7. shows the face slab deflections of the dam as a function of dam height and water level fluctuation for different dam heights and foundations, and to control the effect of the single variable of water level fluctuation, the face slab deflections for similar dam height and foundation conditions in normal CFRDs from the study by Lifeng Wen et al [12-14] is used.

The face slab deflections for almost all dams is less than 0.8%H, while Ming ombs (U) has lager values of face slab deflections, the reason for the face slab deflections value of 1.6%H may be the result of the combination of several unfavorable factors such as its alluvium foundation, the wide valley factor and the large water level fluctuation.The range of dam face slab deflections on rock foundation is 0.29%H to 0.72%H with an average value of 0.47%H, significantly greater than the results of Wen Lifeng et al [12-14]. The average face slab deflections value of the normal CFRD on rock foundations is 0.18%H, which shows the effect of water level fluctuation on the operation of the CFRDs in PSPs. Influenced by foundation settlement, the range of dam face slab deflections on alluvium foundation is 0.04%H to 1.62%H with an average value of 0.537%H, 0.067H% greater than the average value of dams on rock foundations, Compared with the results obtained by Wen Lifeng et al [12-14]. The average dam internal settlement on alluvium foundation is 0.26H% greater than that on rock foundation, and the face slab deflection is less than 0.7% of the total height.The total storge has different effects on the face slab deflection of CFRDs in PSPs on different foundations, with the larger total storge, the face slab deflection on rock foundations are greater, while the opposite is true for dams on alluvium foundation. And it can be seen that the relationship between total storge and face slab deflection is the same as the effect of total storge on crest settlements and internal settlements.

The consideration may be that the influence of foundation on slab deflections is weakened by the overall lower dam height in comparison. The same fit analysis of the data revealed that in the relationship between dam height and face slab deflections under different foundation conditions, the relationship that deformation increases with the increase of dam height is obtained. Considering that the reservoir water level in the process of change is acting directly on the face slab, and in the high water state the face slab is subjected to the load of water to the dam, in the low water state, the bedding layer gives the forces inside the dam body directly outwards to the face slab, so that the face slab will be in a short period of time the role of alternating loads, resulting in the growth of face slab deflection [25-31]. However, it may be that the obtained data on the alluvium foundation dam are too similar in dam height, and the face slab deflections varies greatly, which may have too much randomness and individual differences and is not universal.



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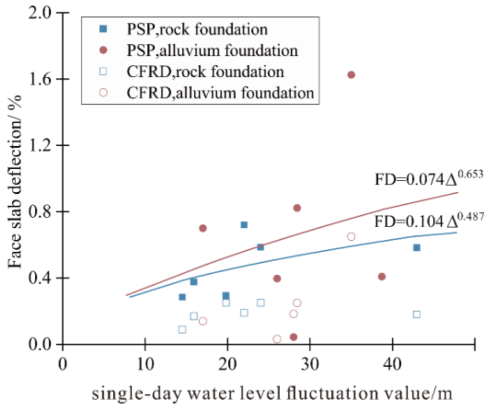

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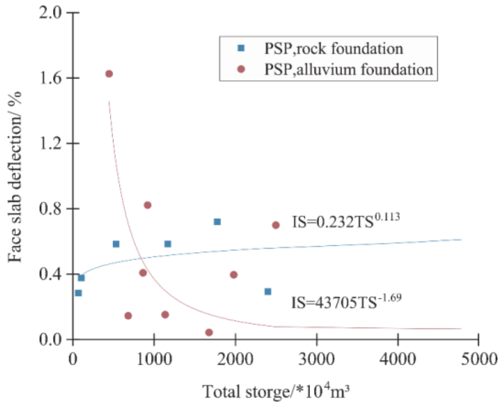


(c)

Fig. 7.CFRD face slab deflections with (a) dam height, (b) single-day water level fluctuation value and (c) total storge

For ordinary CFRDs with similar dam height and foundation conditions and CFRDs inPSPs with large water level fluctuation, it is obvious that large water level fluctuation has an adverse effect on face slab deflections, and CFRDs in PSPs are significantly larger, and for CFRDs in the alluvium foundation face slab deflections will increase with larger water level fluctuation, while there is no such growth for dams on rock foundations. It can also be concluded that large water level fluctuation has a more detrimental effect on the alluvium foundation where the soil is more compressible [15-18].
Scholars concluded that there is a relationship between crest settlements andface slab deflections [25], so that the maximum face slab deflections during reservoir storage can be predicted by crest settlements.From Fig. 8.it can be seen that the face slab deflections and crest settlements are approximately proportional to each other, and most points fall within the distribution area, but Huhhot (U) has a large crest settlement, while the Ming ombs (U) has a large face slab deflection,it may be caused by the material of the dam Rockfill source.It is also found that the data points of the dam on rock foundations are mostly below the straight line i.e. the crest settlements are slightly larger than the face slab deflections, while the dam on the alluvium foundation is the opposite, which is also in line with the general CFRD regularity.

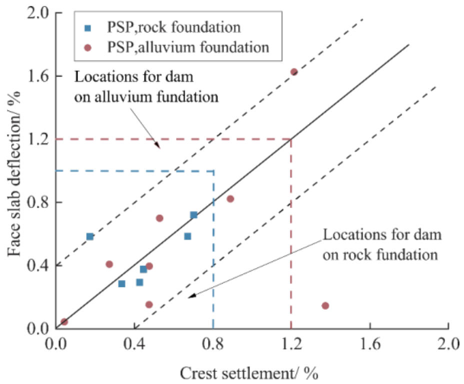
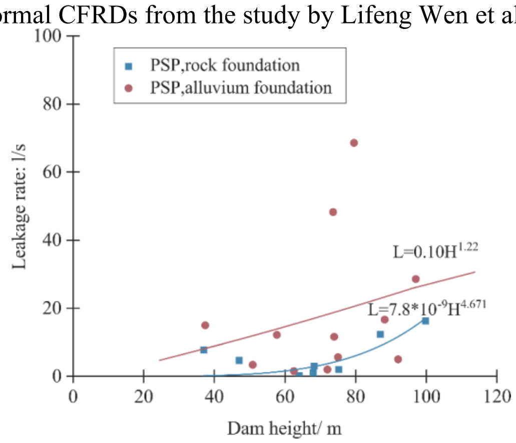


Fig. 8. The relationship between face slab deflections and thecrest settlement

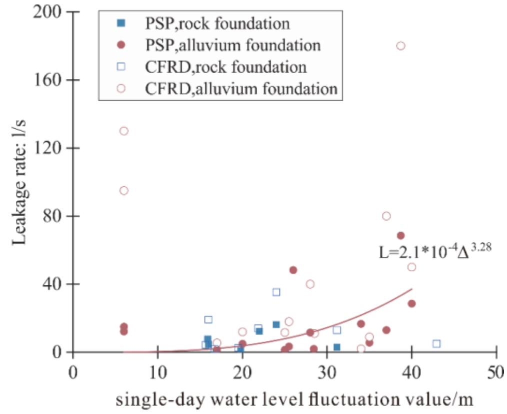
D. CFRDs Leakge

The seepage condition of the dam is directly related to the face slab deflections, rainfall, water level and so on [35-39], while in PSPs, the concern about seepage is mainly due to economic efficiency considerations [5].

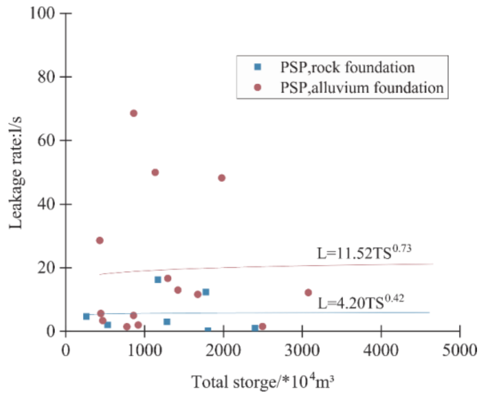
Fig. 9. shows the leakage rate of the dam as a function of dam height and water level fluctuation for different dam heights and foundations, and to control the effect of the single variable of water level fluctuation, the leakage rate for similar dam height and foundation conditions in normal CFRDs from the study by Lifeng Wen et al [12-14]are used.



(a)



(b)



(c)

Fig. 9. CFRD leakage rate with (a) dam height, (b)single-day water level fluctuation value and (c) total storge

As can be seen from the figure, the seepage control system of CFRDs in PSPs is in a better state, with almost most of the dams having small leakage rate, which are basically smaller than those of ordinary CFRDs with similar dam height and foundations, although the leakage rate is still affected by the dam height, water level fluctuation and total storge, which subsequently increase and has a tendency to become larger. However, in any case there are data with very small leakage rates, which, together with too few cases, etc., very much affect the effectiveness of the data fit.

4. Conclusions

This paper investigates dam crest settlements, internal settlements, face slab deflections behavior and leakage rate based on deformation and seepage monitoring data from 32 CFRDs in PSPs, and investigates the effects of dam height, foundation conditions, valley shape factor and water level fluctuation on dam performance. The following conclusions were obtained：

The crest settlements, internal settlements, face slab deflections and leakage rate and seepage of CFRDs inPSPs basically conform to the laws of ordinary CFRDs, but the crest settlements and face slab deflections are larger than those of ordinary CFRDs under the influence of reservouir daily water level fluctuation, while the internal settlements and leakage rate are smaller than those of ordinary CFRDs due to the special topography and high requirements of seepage control standards.

The crest settlements of CFRDs in PSPs is generally 0-1.4%H, and most of the dam face slab deflections are less than 0.8H%. CFRDs in PSPs operate relatively well due to the overall low dam height of the dam. CFRDs properties are mainly influenced by dam height, rockfill strength, foundation characteristics, and valley shape. The CFRDs in PSPSs are almost located in wide river valleys, and both the alluvium foundation and the rockfill material have a negative impact on their stability, and there is an approximately equal relationship between face slab deflections and crest settlements, and leakage rate has a very limited effect on the stability and safety of the dam.

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