Dear Reviewer:

We gratefully thank for your constructive remarks and useful suggestions, which has significantly raised the quality of the manuscript and has enable us to improve the manuscript. Below the comments of the reviewers are response point by point and the revisions are indicated.

Reviewer 1

1. **General Comments:**

I suggest rewriting the abstract section. The current abstract describes too much experimental process, information, and results. These pieces of information are not what readers most want to see, nor are they the most valuable conclusions drawn in this manuscript. Therefore, I suggest the author rewrite the abstract.

1. **Reply:**

We gratefully appreciate for your valuable suggestion. A rewritten abstract is as follows: The numerical experiments investigate the dynamic response of a pile-slab retaining wall under the various impact conditions of rockfall. Results reveal that: (1) during the impact process, the stress, strain, and concrete damage of the structure gradually spread from the impact center to entire structure and ultimately result in permanent deformation; (2) the lateral displacement of pile at the ground surface and the concrete damage under the pile as the impact center is greater than those under the slab as impact center, implying that the impact location has a significant influence on the stability of the structure; (3) there is a positive correlation between the response indexes (impact force, interaction force, lateral deformation of pile and slab, concrete damage, and the impact velocities; (4) within the discussed impact scenarios, the rockfall peak impact force, the ratio of peak impact force to peak interaction force, and lateral displacement of pile at the ground surface had strong linear relationships with rockfall energy. Utilizing this relationship, the estimated maximum impact energy that the pile-slab retaining wall can withstand is 905 kJ in this study when the structure top is taken as the impact point.

2. General Comments:

The manuscript lacks some case studies information and is detached from the case and reality. The numerical simulation results of this manuscript appear to lack basis, greatly reducing their value, and the reliability of the results cannot be verified from real projects.

2. Reply: Thank you for your comment. As illustrated in Fig. 1, pile-slab retaining wall have gained widespread application in various areas. However, challenges persist in their design and construction, notably regarding the maximum impact energy tolerance of structure and the vulnerability of specific components to damage under impact loads. Therefore, comprehensive research is essential to address these issues. This study is based on the modeling of norms and real cases, aiming to reflect the dynamic response characteristics of the structure in the set impact scenario, and provide a basis for the future design, implementation and improvement of the structure.

(a)

(b)

(c)

(d)

(e)

(f)

Fig. 1 pile-slab rockfall retaining wall has been implemented

3. General Comments:

The results obtained from numerical simulation lack in-depth mechanism analysis and in-depth refinement of understanding. The knowledge obtained from the current results and conclusions is similar to that of common sense, and there is no need to carry out this work, as readers can also recognize.

3. Reply: Thank you for your comment. Currently, numerous measures are available for mitigating rockfall disasters, and adapting different forms of protection structures to suit specific engineering contexts is a pivotal challenge. Rockfall impact energy serves as a crucial parameter in this regard. This manuscript determines the impact energy of pile-slab rockfall retaining wall, offering a valuable reference for selecting appropriate rockfall protection structures in the future. Additionally, we have identified a range of structural characteristics under impact loads, providing essential insights for the future design, enhancement, and implementation of such protective structures. Hence, we believe this study holds significant importance.

4. General Comments:

The discussion section of this manuscript is relatively weak. It is recommended that the author, based on reading and referring to a large number of literature, describe the advantages and limitations of the data, models, methods, results, etc. involved in this manuscript.

4. Reply: We gratefully appreciate for your valuable suggestion. A rewritten discussion is as follows:

4. Discussions

Table 1 lists the initial kinetic energy of impactor (E), the peak impact force (F_{dm}), the peak interaction force (F_{im}), the ratio of the peak impact force to the peak interaction force (α), the maximum the lateral displacement of pile at the ground surface at t = 650 ms (S_{mpt}), the number of damage failure units (N_d), and the ratio of damage failure units to overall RC structure units (β).

Table 1 Simulation results for various impact cases.

Case	E (kJ)	F_{dm} (kN)	F_{im} (kN)	α (%)	S_{mpt} (mm)	N_d	β (%)
CP-V10	130	1420	2170	65.4	2.25	83	0.0059
CP-V15	292.5	2188	3008	72.7	3.91	817	0.0577
CP-V20	520	3100	3747	82.7	6.17	2179	0.1539
CP-V25	812.5	4175	4422	94.4	8.8	3088	0.2181
CP-V30	1170	5283	5069	104.2	12.03	5040	0.3559
CS-V10	130	1426	2182	65.4	1.76	52	0.0037
CS-V15	292.5	2196	3015	72.7	3.72	321	0.0227
CS-V20	520	3112	3756	82.7	5.77	1062	0.0750
CS-V25	812.5	4182	4433	94.4	8.7	2728	0.1927
CS-V30	1170	5299	5075	104.2	11.2	4880	0.3446

4.1. Comparison of impact force calculation models

A comparative analysis was performed to evaluate the validity of the calculations in this manuscript, comparing the elastic theories proposed by (Labiouse et al., 1996), Kawahara and Muro (2006), Pichler et al. (2006), and Hertz (1997)with the computational results obtained in this study (Fig. 1). The findings reveal a fundamental linear correlation between impact force and velocity. In general, the computational results in this manuscript align with those of other models of similar magnitude, thereby validating the calculations presented herein.

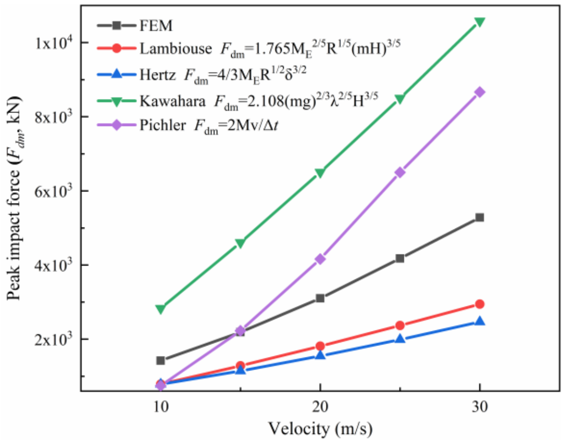

Fig. 1. Relationship between impact velocity and impact force

4.2. Relationship between structural evaluation indexes and impact energy

Under the premise of known impact energy, estimating impact force, interaction force, and displacement for the structural design is very important. As shown in Table 1, the difference of peak impact force (F_{dm}) with different impact centers is minimal, so that CP simulation results were selected to analyze. The dependence of the peak impact force on the impact energy is shown in Fig. 2a, with a correlation coefficient $R^2 = 0.99$, i.e.,

$$F_{dm} = 3.69(E + 290.33) = 1845(mv^2 + 0.58) \quad (1)$$

where E is the initial kinetic energy of impactor, kJ; m is the impactor mass, kg; t (m= 2.6 therein), v is the initial impact velocity, m/s (10 m/s ≤ v ≤ 30 m/s herein).

The dependence of the ratio of peak impact force to peak interaction force on the impact energy is shown in Fig. 2b, with a correlation coefficient of 0.99, i.e.,

$$\alpha = 0.037(E + 1671.89) = 18.5(mv^2 + 3.34) \quad (2)$$

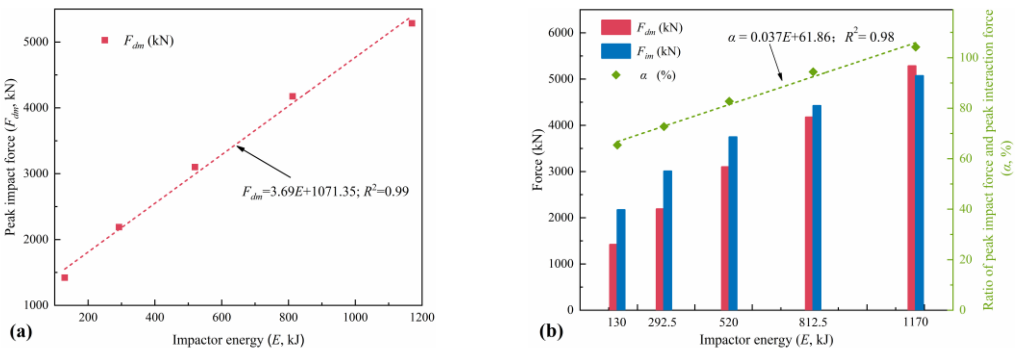

Fig. 2. Dependence of various indexes on impactor energy (a) peak impact force (b) the ratio of peak impact force and peak interaction force.

The lateral displacement of pile at the ground surface is an important index to judge the failure of pile foundation under lateral load. As shown in Table 5, the maximum lateral displacement of pile at the ground surface under pile as impact center is greater than that under slab as impact center. Therefore, the situation where the pile is the center of impact is the more dangerous. As shown in Fig. 3, with the increase of impact energy, the displacement value and number of damage failure units enlarges, which means the structure suffers more damage under CP. Furthermore, the maximum lateral displacement of pile at the ground surface when t = 650 ms, can be calculated by the following aquation:

$$S_{mpt} = 0.00934\left(E + 164.88\right) = 4.67\left(mv^2 + 0.33\right) \quad (3)$$

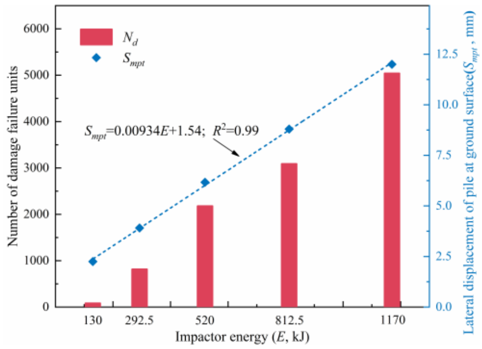

Fig. 3. Dependence of the lateral displacement of 3# pile at the ground surface on impactor energy

According to the Chinese standard Code for the Design of Rock Retaining Wall Engineering in Geological Hazards (Caghp, 2019), the lateral displacement of the resistant sliding pile at the ground surface must not exceed 10 mm. Substituting this value into Formula 3, the maximum impact energy that the PSRW can withstand in this study is 905 kJ.

4.3. Comparison with other concrete rockfall retaining walls

Table 2 illustrates the improved cast-in-place rockfall concrete barrier by the US Department of Transportation demonstrates relatively low maximum impact energy resistance, limiting its suitability to scenarios with large impact energies (Patnaik et al., 2015). The concrete retaining wall with buffering systems, integrating a specialized buffering layer on the traditional retaining wall, effectively enhances the barrier's impact resistance (Kurihashi et al., 2020). Moreover, the energy dissipation ratio indicates that the structural system absorbs all input energy. According to Maegawa et al. (2011), concrete rockfall barriers typically offer a maximum impact resistance ranging from approximately 120 to 490 kJ. In response to the limitations of traditional concrete rockfall barriers in withstanding impact, Furet et al. (2022) proposed the articulated concrete block rockfall protection structures, wherein concrete blocks are interconnected with hinges to enable the structure to absorb higher impact energy as a whole. Regarding energy dissipation, structure damage and friction account for 74% of the impact energy dissipation, while the remaining 26% is presumed to be propagated or dissipated through phenomena such as deformation of structural elements, propagation by elastic waves, dissipation by viscosity under quiet conditions, and fracturing. Compared to the aforementioned concrete rockfall protection structures, PSRW offer significantly higher impact resistance (905 kJ) and interception height (6 m). Similarly, the structure absorbs all impact energy, and the impactor does not rebound.

In the case of concrete deformation damage, Cast-in-place rockfall concrete barriers remain structurally intact under the maximum impact energy, as indicated by the failure model, wherein the concrete retains its integrity despite extensive cracking. Conversely, in articulated concrete blocks rockfall protection structures, concrete damage predominantly occurs locally near the impact point. Notably, under a 520 kJ impact energy, the structure recedes approximately 1.2 m in the direction of impact. For traditional RC retaining walls subjected to a 16 kJ impact energy, cracks develop diagonally upward and downward from the impact point, with wider spreading observed on the back than on the collision surface (Kurihashi et al., 2020). These spreading cracks are interpreted as shear cracks penetrating from the collision plane. **错误!未找到引用源。** illustrates the concrete damage nephogram of PSRW under the impact load of 1170 k. It is evident that concrete damage primarily occurs near the impact point and at the joint of the pile and plate, with no penetration of cracks into the structure. Although the lateral displacement of the pile exceeds the limit, reaching

12mm as indicated in Table 5 and Figure 21, it is essential to note that the ultimate lateral displacement specified in the code is often a conservative estimate. At the same time, the maximum lateral displacement at the crown of the cantilever section is 35mm, which falls significantly below the lateral displacement limit of the cantilever section of the anti-slide pile (set at 1% of the length of the cantilever section) (Caghp, 2019). Consequently, the structure remains unaffected by the impact load.

In summary, PSRW represents a novel rockfall protection structure, offers a higher impact protection grade, greater interception height, and reduced concrete damage. Furthermore, the minimal lateral displacement post-impact ensures structural safety in terrain area.

Table 2 Comparison of different concrete rockfall protection structures

Structure name	The maximum impact energy that structure can withstand (kJ)	Energy dissipation ratio (%)	Interception altitude (m)
Cast-in-place rockfall concrete barriers (Patnaik et al., 2015)	127	/	0.81
Concrete retaining wall with buffering system (Kurihashi et al., 2020)	273	100	2.5
Concrete rock – wall (Maegawa et al., 2011)	490	/	/
Articulated concrete blocks rockfall protection structure (Furet et al., 2022)	1020	100	3.2
Pile-slab retaining wall	905	100	6

Note: Energy dissipation ratio denotes the ratio of dissipated energy to input energy.

Reference

CAGHP: Code for design of rock retaining wall engineering in geological hazards (T/CAGHP060-2019), China University of Geosciences Press, Wuhan2019. (in Chinese)

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