



A Review of Rubber and Hydraulic Cab Mounts for Construction Machinery

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Abstract

Cab vibration remains a persistent problem in construction machinery because these machines usually operate on rough, deformable and non-uniform ground. The excitation transmitted to the cab is often dominated by low-frequency and large-amplitude components, which are difficult to isolate using conventional rubber mounts. Rubber mounts are still widely used because they are compact, inexpensive and reliable, but their fixed stiffness and limited damping make them less effective in controlling cab shaking, pitch and roll vibration. For this reason, hydraulic, hydro-pneumatic, liquid-filled and rubber-hydraulic mounts have been introduced to improve the damping performance of cab isolation systems, especially in the low-frequency range. This review examines 30 representative studies on cab mounts and cab isolation systems for construction machinery and related heavy-duty vehicles. The literature is grouped into passive rubber cab mounts, optimal mount design, hydraulic and rubber-hydraulic mounts, and semi-active cab isolation systems. Particular attention is given to studies on vibratory rollers, soil compactors and wheel loaders, where the interaction between road excitation, machine structure and cab mounting system is more severe than in conventional vehicles. The review shows that rubber mounts remain a practical baseline solution, but hydraulic and rubber-hydraulic mounts provide a more suitable route for improving low-frequency vibration isolation. Semi-active systems can further improve adaptability, although their practical application still depends on durability, control reliability and experimental validation on real machines.

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Keywords: cab vibration isolation, rubber mount, hydraulic mount, rubber-hydraulic mount, construction machinery, wheel loader, ride comfort, whole-body vibration

1. Introduction

Construction machinery is exposed to a vibration environment that is much harsher than that of ordinary road vehicles. Soil compactors, vibratory rollers, wheel loaders and other earth-moving machines often operate on mine roads, construction sites, compacted soil and uneven ground. The excitation is not only random but also closely related to the working process of the machine. A soil compactor is affected by rough ground and repeated compaction forces. A vibratory roller is influenced by both road excitation and drum excitation. A wheel loader is subjected to strong load transfer during digging, lifting, travelling and unloading. Measurements on soil compactors and compact wheel loaders have shown that whole-body vibration exposure must be treated as a comfort and health problem for operators, not only as a mechanical vibration problem ^[1, 2].

The cab is usually mounted on the machine frame by several isolation elements. In principle, these mounts should separate the operator from the vibration of the chassis. In practice, this task is not simple. The most difficult vibration is often located in the low-frequency range, where the human body is sensitive and where passive isolation becomes less effective.

Sun and Zhang pointed out that low-frequency shaking is a typical problem of construction machine cabs, and that the isolator design must be considered together with the dynamic characteristics of the cab-frame system^[3]. Their later study on earth-moving machinery also showed that hydraulic mounts can improve low-frequency vibration performance compared with conventional rubber mounts^[4].

Rubber mounts are still used widely because they are simple, inexpensive and robust. They carry the static load of the cab, allow a certain displacement between the cab and the frame, and reduce part of the vibration transmitted to the operator. For machines working in mud, dust and impact conditions, this simplicity is a real advantage. However, rubber mounts also impose an important limitation. Their stiffness and damping are almost fixed after installation. If the mount stiffness is too high, vibration is transmitted directly to the cab. If the stiffness is too low, the cab may experience excessive motion, especially in pitch and roll. A number of studies on cab mounting design and agricultural machine cab suspension have shown that mount position, stiffness and damping must be selected carefully to improve operator comfort^[5-7].

Hydraulic and rubber-hydraulic mounts were developed to deal with the low damping limitation of rubber mounts. A hydraulic mount keeps the elastic support function of rubber but adds a fluid chamber, an orifice or an inertia track. When the mount is excited, fluid flow produces a pressure difference, and this pressure difference generates additional damping. This mechanism is useful for low-frequency cab shaking because damping can be increased near the resonance range of the cab system. Recent studies on hydraulic damping rubber mounts have shown that both excitation frequency and excitation amplitude affect the dynamic behavior of the mount^[8, 9]. The use of an inertia track further allows the mount to be tuned for a target low-frequency range^[10]. For soil compactors, the optimal design of a cab hydraulic mount has also been studied as a practical way to improve ride comfort^[11].

The same idea can be extended to fluid-filled mounts and hydraulic body mounts. Fluid-filled cab mounts have been modeled using multi-physics approaches, while hydraulic body mounts have been applied to reduce low-frequency shake in other heavy vehicle applications^[12, 13]. Although not all of these studies are on construction machinery, they are useful because the physical mechanism of fluid damping is similar. More advanced solutions include semi-active and controllable mounts. A semi-active magneto-rheological mount for a wheel loader cabin was designed to change its damping characteristics according to control input^[14]. Hydro-pneumatic and semi-active cab suspensions have also been evaluated for tractors, while active cab suspension has been considered for heavy machines^[15, 16].

Recent optimization and data-based approaches have also been used to improve cab vibration comfort. For example, multi-target regression forests have been applied to optimize cab vibration comfort in construction machinery^[17]. Related studies on truck cab suspension, although outside the direct scope of construction machinery, provide useful information on cab suspension configuration, mount location and ride comfort evaluation^[18-20]. These works are valuable because cab comfort depends not only on mount stiffness or damping but also on the layout of the cab suspension system and the coupling between vertical, pitch and roll motion.

A continuous research line on off-road vibratory rollers,

earth-moving machinery and wheel loaders has also been developed by Le Van Quynh and co-authors. Their work covers review studies, vibration analysis, optimal design, experimental modal analysis, semi-active hydraulic cab mounts and liquid-filled cab isolation systems^[21-30]. This group of studies is particularly relevant to the present review because it connects the development route from rubber mounts to hydraulic and semi-active systems for actual construction machinery.

This paper reviews rubber and hydraulic mounts for construction machinery. The purpose is not only to summarize previous publications but also to clarify the technical development route. The discussion follows the sequence from passive rubber mounts to hydraulic and rubber-hydraulic mounts, and then to semi-active systems. The review also identifies the remaining problems that should be addressed before advanced cab isolation systems can be widely applied to machines such as wheel loaders, vibratory rollers and soil compactors.

2. Literature Classification and Review Method

The literature was selected based on its relevance to cab vibration isolation, mount design and construction machinery ride comfort. Three types of studies were considered. The first type includes studies that describe the vibration environment of construction machinery and evaluate operator exposure. The second type includes studies that analyze and optimize passive cab mounts. The third type includes studies on hydraulic, rubber-hydraulic, liquid-filled and semi-active mounts.

The reviewed papers can be divided into two groups. The first group consists of international studies on construction machine cabs, hydraulic mounts, agricultural cab suspension, truck cab suspension and controllable mounts^[1-20]. The second group consists of studies by Le Van Quynh and co-authors on vibratory rollers, soil compactors, earth-moving machinery and wheel loaders^[21-30]. This arrangement is useful because it allows the review to combine the broader international background with a focused research line on construction machinery.

From the technical viewpoint, the literature can be classified into four main directions.

The first direction deals with the vibration environment and ride comfort assessment. Studies on soil compactors and compact wheel loaders show that the operator is exposed to a combination of vertical vibration, pitch and roll motion^[1, 2]. These studies are important because they define the practical problem before mount design is considered. If the excitation source and the dominant vibration direction are not clear, the design of the isolation system may become only a parameter tuning exercise.

The second direction focuses on passive rubber mounts and mount optimization. Rubber mounts are usually represented by stiffness and damping parameters in dynamic models. These parameters, together with mount location, affect the cab natural frequencies and vibration responses. Studies on cab mounting design and agricultural cab suspension show that the isolation system should be optimized according to comfort criteria instead of being selected only from static load requirements^[5-7]. For construction machinery, this point is even more important because the cab response includes not only vertical motion but also pitch and roll.

The third direction concerns hydraulic and rubber-hydraulic mounts. This group is central to the present review. The main

issue is how to use fluid damping to reduce low-frequency cab vibration. Hydraulic damping rubber mounts have been modeled and tested under large-amplitude excitation [8, 9]. This is a necessary step because construction machinery mounts rarely work under small and ideal harmonic excitation. The introduction of an inertia track further improves the possibility of tuning the mount response in the low-frequency range [10]. For soil compactors, hydraulic mount damping has also been optimized to improve ride comfort [11].

The fourth direction is related to semi-active and controllable systems. Passive hydraulic mounts can improve damping, but their characteristics are still fixed after design. Semi-active systems try to overcome this limitation by adjusting the damping force according to the working condition. Studies on magneto-rheological mounts, hydro-pneumatic systems and active cab suspensions show the potential of controllable isolation systems [14-16]. However, these systems also introduce new issues, such as sensor reliability, control robustness, cost and maintenance.

The studies by Le Van Quynh and co-authors form a relatively complete development sequence. A review on cab isolation systems of off-road vibratory rollers summarized the transition from passive rubber mounts to hydraulic and semi-active systems [21] (see Fig.1). Earlier studies analyzed the vibration and optimal design of cab isolation systems for vibratory rollers [22, 23]. Later work compared different cab isolation mounts and used experimental modal analysis to support the optimal design of single-drum vibratory roller cab systems [24-26]. Semi-active hydraulic cab mounts were then investigated for double-drum vibratory rollers and earth-moving machinery [27, 28]. More recent studies extended the topic to wheel loaders using hydraulic and liquid-filled cab isolation systems [29, 30].

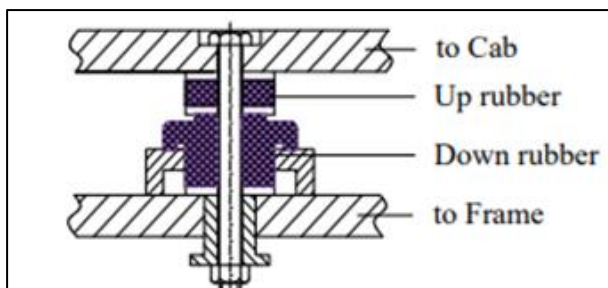


Fig 1: Conventional rubber cab mount [21]

This classification shows that the research field has not moved away from rubber mounts completely. Instead, rubber mounts remain the baseline structure, and hydraulic elements are added when additional low-frequency damping is required. Semi-active mounts appear when passive hydraulic characteristics are still not flexible enough. This gradual development is important for construction machinery because the best solution is not always the most complex one. A practical cab isolation system must reduce vibration, but it must also be durable, compact and suitable for real operating conditions.

3. Rubber Cab Vibration Mount

Rubber cab mounts are the basic solution for most construction machinery. Their role is to support the cab and reduce vibration transmission from the frame. A rubber mount usually has a simple structure, including a rubber

element bonded to metal plates or sleeves. In dynamic models, it is often simplified as a spring-damper element. This simplification is convenient, but it only captures the main behavior of the mount. In reality, rubber has nonlinear stiffness, frequency-dependent characteristics and amplitude-dependent damping.

The practical advantage of rubber mounts is clear. They are cheap, compact and reliable. They can work in dirty environments and require little maintenance. They also have a fail-safe nature because even when their performance degrades, they can still support the cab. These features explain why rubber mounts are still widely used in construction machinery. A sophisticated mount that performs well in simulation may not be attractive if it is difficult to install or if it cannot survive impact, mud, oil and temperature variation.

The weakness of rubber mounts appears mainly in the low-frequency range. Passive isolation depends strongly on the ratio between excitation frequency and natural frequency. Below or near the natural frequency of the cab-mount system, vibration is difficult to isolate. In some cases, the mount may even amplify vibration. Increasing mount damping can reduce resonance, but too much damping may reduce the isolation effect at higher frequencies. This trade-off is well known in passive vibration isolation and is especially important for construction machinery cabs.

The cab response is also multi-directional. Vertical acceleration is important, but pitch and roll cannot be ignored. In a wheel loader, pitch motion may be caused by load transfer during digging and braking. In a vibratory roller, the excitation from the drum can excite both vertical and angular motion. In a soil compactor, rough ground and machine structure can produce combined vibration. Therefore, the design of a cab isolation system should not be based only on one vertical acceleration index. A good design must consider the coupled response of the seat, cab and machine frame.

Optimal mount design is one way to improve rubber cab isolation systems. Mount stiffness, damping coefficient and mounting position can be selected to reduce cab resonance and improve comfort. The studies on cab mounting design show that mount parameters strongly affect the vibration transmitted to the operator [5]. Work on agricultural cab suspension also indicates that a mathematical model is useful for selecting mount parameters and optimizing operator comfort [6, 7]. These studies provide useful methods for construction machinery, even though the machine structures are different.

For vibratory rollers, Le Van Quynh and co-authors developed several studies on passive cab isolation. In the early study, the cab isolation system of a vibratory roller was analyzed and optimized to improve ride comfort [22]. The later study using a multi-objective genetic algorithm is particularly relevant because it considered more than one vibration response [23]. This is a better approach for construction machinery than optimizing only vertical seat acceleration. In practice, the operator feels vertical vibration together with cab pitch and roll. If one response is reduced but another response increases, the overall comfort may not improve (see Fig.2).

The comparison of different cab isolation mounts for an off-road vibratory roller provided another useful step [24]. Such comparisons are valuable because the performance of a mount should be judged under the same machine and

excitation conditions. Experimental modal analysis was then used to identify the vibration characteristics of a single-drum vibratory roller cab [25]. This is important because optimization without experimental identification may lead to mount parameters that work only in the model. The following study on optimal design for a single-drum vibratory roller continued this research direction [26].

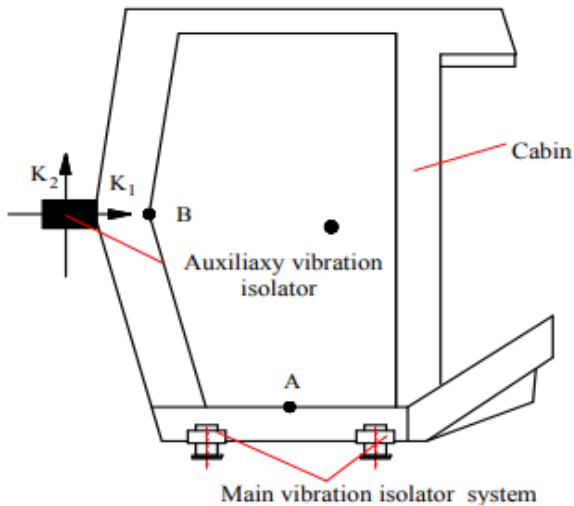


Fig 2: The main and auxiliary RCVI systems for a vibratory roller [22]

From these studies, three comments can be made. First, rubber mounts should not be treated as a poor solution. They are still necessary and practical for many machines. Second, their performance depends strongly on correct design. A poorly selected rubber mount can increase low-frequency cab motion. Third, even optimized rubber mounts remain passive. They cannot adapt to large changes in speed, road roughness, payload or working mode. This limitation explains why hydraulic and rubber-hydraulic mounts have become an important research direction.

4. Rubber-Hydraulic Cab Vibration Isolation (R-HCVI) Systems

Hydraulic mounts were introduced because rubber mounts alone cannot provide enough damping in the low-frequency range. The basic idea is to combine elastic support and hydraulic damping in one mount. The rubber part carries the static load and provides elastic stiffness. The hydraulic part uses fluid flow through an orifice or inertia track to generate additional damping. When the cab moves relative to the frame, pressure difference is created between fluid chambers. The flow resistance then dissipates energy.

This mechanism is well suited to low-frequency cab shaking. Near the resonance range, the cab needs additional damping to limit excessive motion. Rubber material damping is often not enough. A hydraulic mount can increase damping without relying only on rubber hysteresis. Sun and Zhang showed that hydraulic mounts can improve the low-frequency performance of earth-moving machinery cabs [4]. Their result supports the idea that the improvement of cab isolation should not focus only on lowering stiffness. Damping generation is equally important.

A key difficulty is that construction machinery excitation is often large in amplitude. Many mount models are developed under small-amplitude assumptions. However, a cab mount

on a wheel loader or soil compactor may experience large relative displacement when the machine works on rough ground. Liao *et al.* studied hydraulic damping rubber mounts under larger amplitude excitation and showed that the mount response depends on amplitude as well as frequency [8,9]. This point is important for engineering design. A mount that behaves well in small-amplitude laboratory tests may not perform in the same way during real machine operation.

The inertia track is another useful feature in rubber-hydraulic mounts. By designing a fluid passage with a specific length and cross-section, the mount can produce frequency-dependent dynamic stiffness and damping. Liao *et al.* showed that a hydraulically damped rubber mount with an inertia track can be modeled and tested for low-frequency performance [10]. For cab isolation, this means the mount can be tuned around the dominant cab shaking frequency. The limitation is that the tuning range is still fixed. If the dominant excitation changes, the passive inertia-track mount may no longer be optimal.

Hydraulic mounts can also be designed as an improved version of existing rubber mounts. Li studied the damping characteristics and optimal design of a cab hydraulic mount for a soil compactor [11]. This direction is practical because it does not require a complete redesign of the cab-frame structure. For construction machinery manufacturers, this is an important advantage. A mount that can be installed in the original mounting space is easier to apply than a completely new suspension layout.

Fluid-filled mounts and hydraulic body mounts provide additional background for this field. Farjoud *et al.* used multi-physics modeling to study a cab suspension system with fluid-filled mounts [12]. Lee *et al.* applied hydraulic body mounts to reduce low-frequency shake in pickup trucks [13]. These studies are not all focused on construction machinery, but their physical principles are still relevant. Low-frequency shakes are a common problem in many vehicle types, and fluid damping is one effective way to control it.

The application to wheel loaders deserves special attention. A wheel loader usually has a stiff structure and works under repeated loading conditions. The cab is strongly influenced by the motion of the frame and the working attachment. Huan *et al.* evaluated a cab hydraulic isolation system for a wheel loader [29]. More recently, a full-vehicle nonlinear dynamic model was developed to study the effect of liquid-filled cab vibration isolation on wheel loader ride comfort [30]. The use of a full-vehicle model is important because the cab response cannot be separated completely from tire deformation, frame motion and seat dynamics.

Semi-active systems are a natural extension of hydraulic mounts. In passive hydraulic mounts, the damping characteristic is fixed by the orifice, fluid and chamber geometry. In semi-active mounts, the damping force can be adjusted. Yang *et al.* designed and evaluated a semi-active magneto-rheological mount for a wheel loader cabin [14]. Magneto-rheological fluid can change its apparent viscosity under a magnetic field, allowing the mount to change its damping level. This is attractive for construction machinery because road condition, payload and working mode are not constant.

Hydro-pneumatic and semi-active cab suspension systems have also been studied for agricultural tractors [15]. Although tractors are not construction machinery, the vibration environment has several similarities, including low speed, rough ground and low-frequency excitation. Tora studied

active suspension for a heavy machine cab, which indicates another possible development direction^[16]. However, active and semi-active systems are not simple to apply. They need sensors, controllers, power supply and reliable actuators. These components must operate in harsh environments. If the system is too complex or not robust enough, the practical advantage may be lost.

The studies by Le Van Quynh and co-authors also support the development of semi-active hydraulic cab isolation. A semi-active hydraulic cab mount system was evaluated for a

double-drum vibratory roller^[27]. Another study proposed a semi-active cab isolation system for earth-moving machinery^[28] (see Fig.3). These works show that adjustable damping can improve ride comfort when compared with fixed passive systems. The main engineering question is how to select the damping force in real time. A controller that increases damping at resonance may reduce cab motion, but excessive damping can transmit more high-frequency vibration. Therefore, the control law must be designed with both comfort and isolation in mind.

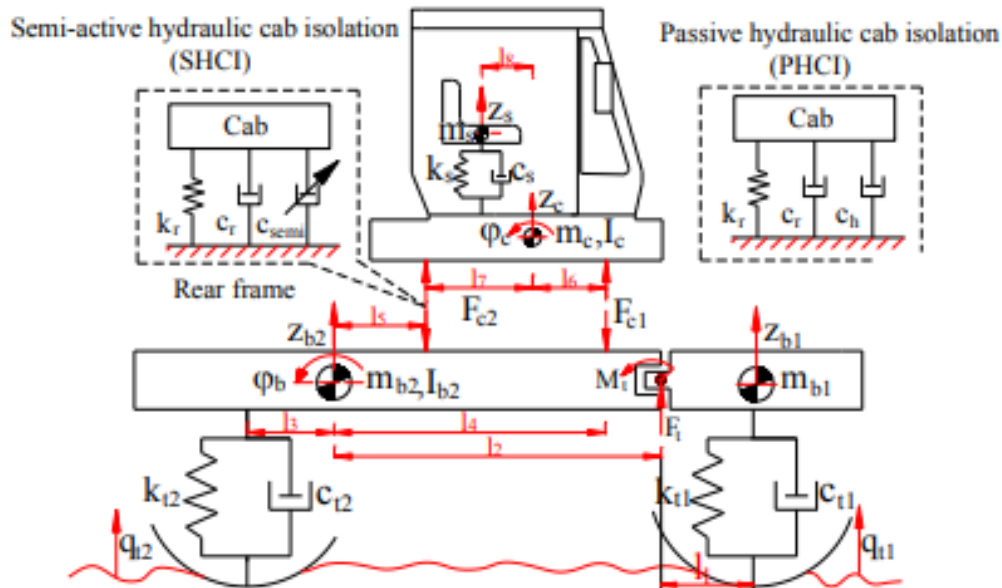


Fig 3: A vehicle-road coupled interaction model of a wheel loader with PHCI and SHCI^[28]

A fair comparison between rubber and hydraulic systems should consider four aspects.

First, rubber mounts are better in simplicity and durability. They are inexpensive, compact and easy to maintain. For machines where vibration is moderate, optimized rubber mounts may be sufficient.

Second, hydraulic and rubber-hydraulic mounts are better in low-frequency damping. They can control cab shaking more effectively because energy is dissipated through fluid flow. This advantage is most evident when the cab works near resonance.

Third, semi-active systems provide better adaptability. They are suitable for machines that operate under strongly variable conditions. However, their performance depends on control reliability, sensor quality and actuator durability.

Fourth, practical application should not be judged only by vibration reduction. Leakage, temperature sensitivity, fatigue life, installation space, manufacturing cost and maintenance must also be considered. For construction machinery, these practical factors often decide whether a mount can be used in production.

The reviewed literature suggests that rubber-hydraulic mounts may be a balanced solution for many construction machines. They retain the basic robustness of rubber mounts while adding hydraulic damping to reduce low-frequency vibration. Semi-active systems are more advanced, but they are better suited to high-value machines or special applications where the additional cost and complexity can be justified.

5. Conclusions

This review examined rubber and hydraulic mounts for construction machinery based on 30 representative studies. The literature shows a clear development route from passive rubber mounts to hydraulic, rubber-hydraulic and semi-active systems. Rubber mounts remain the baseline solution because they are simple, durable and easy to install. Their main limitation is the weak low-frequency damping, especially when the cab is excited by large-amplitude road input or machine working forces.

Optimal design of rubber mounts is still necessary. The stiffness, damping coefficient and mounting position should be selected according to the coupled response of the cab, seat and frame. Studies on vibratory rollers show that multi-objective optimization is more appropriate than single-index optimization because cab vertical vibration, pitch and roll can all affect comfort. However, optimized rubber mounts cannot overcome the passive nature of the system. Once the road condition, speed or payload changes, the mount parameters may no longer be suitable.

Hydraulic and rubber-hydraulic mounts provide a more effective solution for low-frequency cab vibration. By using fluid chambers, orifices and inertia tracks, these mounts can generate additional damping near the cab shaking frequency. Studies on earth-moving machinery, soil compactors and wheel loaders show that hydraulic damping is especially useful when rubber mounts cannot control resonance adequately. The difficulty is that hydraulic mounts are more complex and may be affected by leakage, temperature variation and durability issues.

Semi-active hydraulic and magneto-rheological mounts are promising because they can adjust damping according to operating conditions. They are suitable for construction machinery working under variable terrain and load. Nevertheless, their application still requires careful evaluation. The mount structure, controller, sensor system and actuator must be reliable enough for harsh working environments. Without real-machine validation, the advantage shown in simulation may not be convincing.

Several research gaps can be identified. First, many studies still rely on simplified cab or half-vehicle models. For wheel loaders and other construction machines, full-vehicle nonlinear models are needed to describe the coupling among tire, frame, cab, seat and working attachment. Second, experimental validation under real operating conditions is still limited. Laboratory tests are useful, but they cannot fully represent off-road excitation. Third, comparisons among rubber, hydraulic, rubber-hydraulic and semi-active mounts should be performed under the same excitation conditions. Fourth, future studies should evaluate not only vertical seat acceleration but also cab vertical acceleration, pitch and roll. Finally, durability, leakage, cost and installation constraints should be included in the design discussion.

For future research, a practical direction is to combine full-machine modeling, field measurement and multi-objective optimization. The evaluation should use both mechanical vibration indices and operator comfort criteria. For wheel loaders, the loading cycle should be considered because the vibration during loading, travelling and unloading can be different. For vibratory rollers and soil compactors, the interaction between road excitation and working excitation should be included. For hydraulic and rubber-hydraulic mounts, the design should aim at a balance between vibration reduction, reliability and manufacturability.

In summary, rubber cab isolation systems are still necessary, but they are not sufficient for severe low-frequency cab vibration. Hydraulic and rubber-hydraulic mounts provide better damping and are more suitable for harsh off-road operating conditions. Semi-active systems offer a higher level of adaptability, but their practical use depends on robust control and real-machine validation. The next stage of research should therefore move from proposing mount structures to proving their effectiveness on actual construction machinery.

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