# Design and Implementation of an Explorer Robot Suspension Based Rocker-Bogie Mechanism

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## ABSTRACT

***Robots are essential in the industrial sector, especially when it comes to surveying and ensuring safety. There is an increasing need for robots that can navigate and work in challenging and dangerous environments, which are difficult for humans to access. As a result, the researchers are actively studying and developing an explorer robot using a rocker-bogie suspension system. To create the suspension model, the researchers used computer-aided design-based analysis in SolidWorks and finite element analysis (FEA) to evaluate its structural strength. Before commencing construction, it is critical to simulate the suspension movement of the explorer robot. The explorer robot's study findings and design have dimensions of 52, 100, and 37 cm, as well as a weight of 35.90 kg. Under the specified conditions, the analysis of the explorer robot structural strength of suspension revealed a maximum stress concentration of 14.538 MPa, along with a safety value factor of 16.852. The suspension of explorer robot design accommodates a required load of 2,479 N. In addition, the researchers conducted simulations to model the physical characteristics of movement in various scenarios. The suspension of an explorer robot retains its original design features.***

***Keywords:*** *Explorer Robot, Rocker-Bogie Mechanism, Finite Element Analysis*

## 1. INTRODUCTION

Over the past decade, robots have played a pivotal role in the industrial sector, particularly in tasks related to surveying and safety. There is a growing demand for robots capable of navigating uneven terrain and hazardous environments that are inaccessible to humans. To effectively fulfill these missions, such robots require suitable mobile equipment [1]. Among the various mobile systems available, the rocker-bogie suspension system emerges as a preferred choice. The first use of this suspension system was for the Mars rovers, mechanical robots sent on the Mars Pathfinder mission, and subsequently for the Mars Exploration Rover and Mars Science Laboratory missions. Space exploration vehicles have long improved the rocker-bogie suspension system. The rocker-bogie suspension system, currently NASA's preferred design for rovers, is a mechanism that drives a six-wheeled vehicle with a differential and maintains all six wheels in good contact with the surface. This feature offers two significant advantages, especially when traversing severely uneven terrain. Firstly, it ensures balanced force distribution of the wheels on the ground. Secondly, when encountering obstacles on uneven terrain, all six wheels remain in contact with the surface under load, facilitating the vehicle's traversal over the terrain. The rover capitalizes on this layout by integrating each wheel with a drive actuator, thereby maximizing maneuverability and enabling the vehicle to navigate extremely rough terrain [2] – [5].

Nowadays, numerous research investigations demonstrate the importance of using finite element analysis (FEA) in order to evaluate the structure of suspension and assess its strength. The study plays an essential role in identifying potential strengths and improving the design of components to enhance their durability [6]. FEA enhances the ability to design and analyze complex systems accurately, efficiently, and safely, which is crucial in modern engineering practices. For instance, Nuñez Quispe et al. (2021) [7] devised a rover prototype tailored for Mars exploration and analogous extraterrestrial environments, employing FEA to validate its mechanical design and transient dynamics. Similarly, Seralathan et al. (2020) [8] engineered a bogie-rocker mechanism chair, scrutinizing its structural integrity through computer-aided design (CAD)-based analysis in ANSYS software. Their investigation encompassed parameters like hydrostatic pressure, equivalent stress, and deformation. Sinha and Sinha (2018) [9] pursued an uncomplicated yet efficient rocker-bogie mechanism, employing calculations and CATIA design alongside rubber thread-bound wheels. They further substantiated their approach through ground-level experiments, showcasing the mechanism's capability to ascend stairs and inclines. Singh et al. (2019) [10] delved into FEA-based analysis of vibration characteristics and resonance frequency determination for the bogie-rocker mechanism. Their study encompassed modal analysis for deformation and delineating failure thresholds through carefully selected boundary conditions.

Therefore, the researchers employ CAD-based analysis in SolidWorks for designing the rocker-bogie mechanism and conducting FEA to ensure structural robustness. Subsequently, the researchers implement the suspension system into an explorer robot prototype and evaluate its performance under various conditions, aiming to advance robotic exploration capabilities. The researchers ultimately conclude that the newly developed suspension system significantly improves the ability of an explorer robot to traverse challenging terrain.

## 2. RESEARCH METHODOLOGY

The research methodology for this study comprises four main stages: geometry design, strength analysis, implementation, and movement simulation.

(1) *Design*: The rocker-bogie suspension system is designed using SolidWorks, with careful consideration of geometric parameters and mechanical components. The assembly is modeled to simulate real-world behavior, ensuring accuracy in performance predictions.

(2) *Strength analysis*: SolidWorks Simulation conducts finite element analysis to assess the structural strength of suspension system under load conditions. This analysis aids in identifying potential weaknesses and optimizing component designs for enhanced durability.

(3) *Implementation*: This step involves creating a prototype of an explorer robot using rocker-bogie suspension. It uses design and strength analysis to create a real work piece.

*(4) Physical characteristics of movement*: This study used SolidWorks Motion to simulate the physical characteristics of stair-climbing by exploration robots, taking into account the stairs size, step height, and tread width, in accordance with the Department of Civil Engineering and Urban Planning's specifications.

### 2.1 Detailed explanation of the Rocker-Bogie Mechanism

Vehicles, particularly robotic explorers like Mars rovers, use rocker-bogie suspension, a type of multi-wheel suspension system. A frame connects a rocker and a bogie. The term "rocker" epitomizes the rocking motion of the larger links on each side of the suspension system, crucial for balancing the bogie. A selectively modified differential mechanism interconnects these rockers with each other and the vehicle chassis. According to the motion necessary to maintain the entire vehicle's center of gravity, when one rocker moves up, the other goes down. The chassis assumes a pivotal role in maintaining the average pitch angle of both rockers, allowing them to adjust according to the terrain. This intricately designed system affixes one end of a rocker to a drive wheel, pivots the other end to a bogie, and provides the necessary motion and degree of freedom. The "bogie" refers to the connecting links with drive wheels at each end. Military tanks initially used bogies to distribute loads in their tracks, but they also found widespread use on semi-trailer truck trailers, facilitating the transport of heavier loads [11] – [12].

Discussing the geometry parameters of the rocker-bogie suspension is essential to establishing the tuning parameters. Fig. 1 illustrates these parameters clearly. Achieving the five key geometric design points of the rocker-bogie suspension is $O_1$, $O_2$, $W_1$, $W_2$, and $W_3$, along with locating the center of mass (CM), specifying the wheel radius, and defining the wheel width. They reflect the relative positional relationships among those key points. These two angles make up the main rocker branch angle. To change these two angles, the researchers use the angle-adjusting mechanism. The rover has no concern about its width. The requirements for the surrounding area generally determine its width.

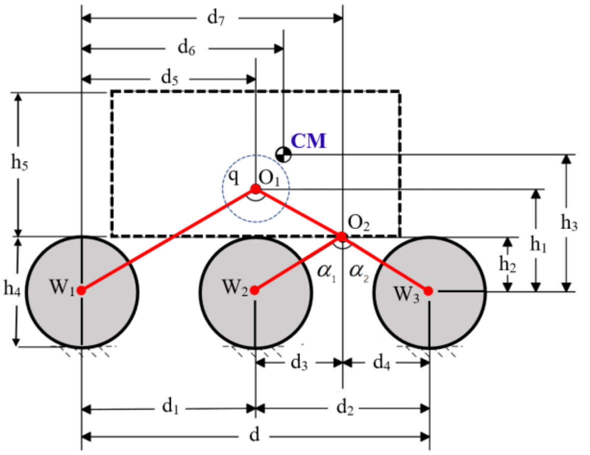


***Fig. 1*** *Geometry parameters of rocker-bogie suspension*

The geometry parameters of rocker-bogie suspension system play a crucial role in achieving optimal wheel locomotion performance. These parameters serve as descriptors for the necessary performance criteria. Despite the overwhelming number of parameters, the researchers can determine many of them using design specifications or common criteria for rocker-bogie suspensions. These requirements, derived from the geometric parameters, are critical for design of the rocker-bogie suspension.

(1) The distance between the center of mass (CM) and output shaft axle $O_1$ affects the differential mechanism design. It should be as short as possible: $d_5$–$d_6$. Furthermore, this is required for realizing front and rear wheel lifts.

(2) When the rover is moving across flat ground, the normal force distribution on one wheel should be the same as that on any other wheel. The horizontal separation between $O_1$ and $W_1$ is twice that of $O_1$ and $O_2$, while the horizontal separation between $O_2$ and $W_2$ is equal to that of $O_2$ and $W_3$. $d_3 = d_4$ and $d_5 = 2(d_7 - d_5)$.

(3) The rover should have similar forward and backward traverse abilities; as such, the wheel axle distance between the rear and middle wheels is equal to that between the middle and front wheels ($d_1 = d_2$).

(4) For heat preservation, the output shaft should be contained in the body, particularly when mechanisms are added to it: $h_1 + q < h_4 + h_5$ and $h_1 - q < h_3$.

(5) Generally, the axle distance ($d_1$ for the front wheels and $d_2$ for the rear wheels) exceeds the wheel diameter (d). Additionally, researchers typically set the distance between the front wheels and middle wheels equal to the distance between the middle wheels and the rear wheels [13].

***Table 1.*** *Geometry parameters of rocker-bogie suspension.*

| No. | Geometry Parameters | Length (mm) |
|---|---|---|
| 1 | d | 800 |
| 2 | $d_1$ | 400 |
| 3 | $d_2$ | 400 |
| 4 | $d_3$ | 200 |
| 5 | $d_4$ | 200 |
| 6 | $d_5$ | 400 |
| 7 | $d_6$ | 450 |
| 8 | $d_7$ | 600 |
| 9 | $h_1$ | 176 |
| 10 | $h_2$ | 118 |
| 11 | $h_3$ | 290 |
| 12 | $h_4$ | 270 |
| 13 | $h_5$ | 180 |
| 14 | b | 520 |

Based on the rocker-bogie suspension design data, as shown in Table 1, when designing and prototyping with SolidWorks, the researchers designed rocker-bogie suspensions as curved features to reduce stress and make the designs more unique, as shown in Fig. 2.

Fig. 3 shows the modeling of the explorer robot using rocker-bogie suspension, along with details of the rocker-bogie suspension system, including the rocker, bogie, differential mechanism, wheel, and pivot.

### 2.2 Strength analysis

Finite element analysis (FEA) is a technique for evaluating material strength. It employs mathematical principles to tackle a broad spectrum of issues by numerically resolving systems of partial differential equations. FEA uses specialized software to break down the problem's geometry into connected elements and then calculates to determine the values of variables. It comprises four components: the geometry of model, material parameters defining the properties of the material under study, boundary conditions that establish limits, and the applied load or force. Additionally, FEA greatly diminishes the time and costs linked to producing realistic simulations and offers the advantage of conducting experiments repeatedly. The essential steps of FEA include three main stages: (1) the pre-processing phase, (2) the solution phase, and (3) the post-processing phase, each vital for precise analysis and interpretation of simulation outcomes [14].

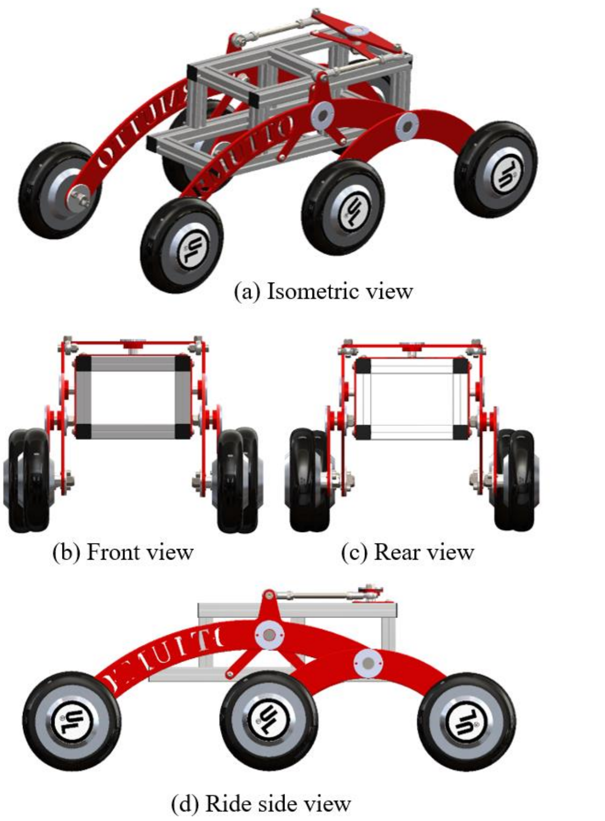


***Fig. 2*** *Structure design of an explorer robot by using rocker-bogie suspension*

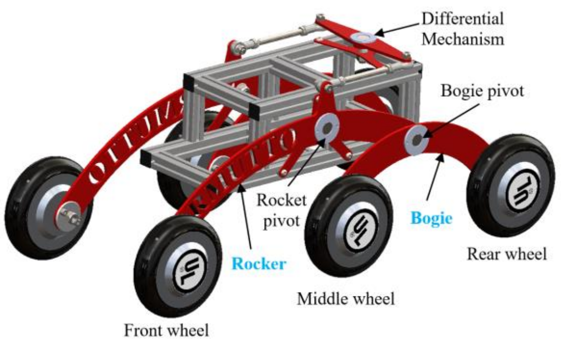


***Fig. 3*** *Modeling of rocker-bogie suspension*

***Table 2*** *The properties of materials used in this research.*

| Property | Value | |
|---|---|---|
| | *Carbon steel SS400* | *Aluminum alloy AA6082-T6* |
| Elastic modulus (GPa) | 210 | 68.9 |
| Poisson's ratio | 0.26 | 0.33 |
| Mass density (kg/m$^3$) | 7,860 | 2,700 |
| Tensile strength (MPa) | 300 | 310 |
| Yield strength (MPa) | 245 | 276 |
| References | [15] | [16] |

The strength analysis utilized a SolidWorks simulation to assess the strength of structure. Its goals were to determine the maximum stress (von Mises stress) and evaluate the factor of safety (FOS) using FEA. The researchers are defined as having a maximum weight of 15 kg, according to the design conditions. The researchers base this on the weight of the maximum structure that needs support, excluding the weight of the wheels. A joint frame connects a rocker and a bogie, which are fixtures for analysis (see Fig. 4). Additionally, researchers have studied the weight distribution on each wheel of an explorer robot. This study calculates the reaction force using weight equations and finds it equal to 147.105 N, indicating the explorer robot is in balance. Fig. 5 illustrates the position of the reaction force.

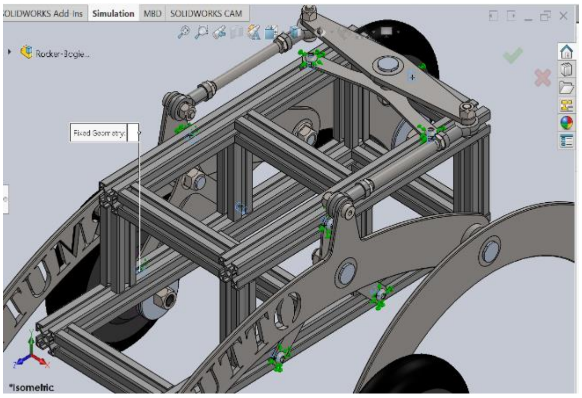

***Fig. 4*** *Define the position of the fixed geometry*

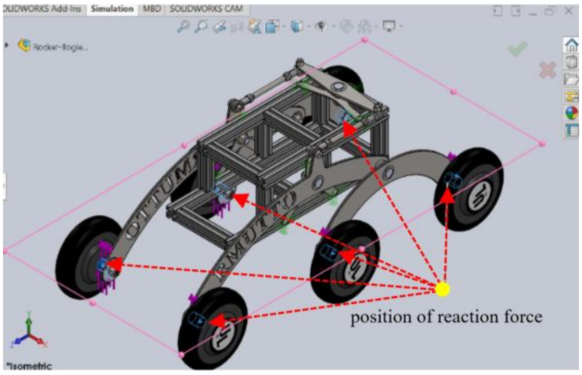


***Fig. 5*** *Define the position of the reaction force*

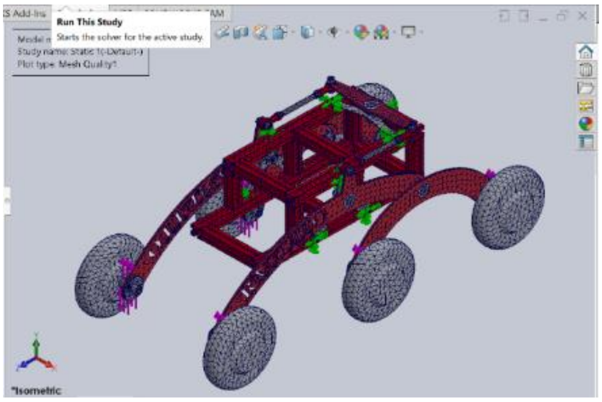

***Fig. 6*** *Meshing of an explorer robot*

Fig. 6 shows the structure of the explorer robot based on rocker-bogie suspension, which is carbon steel (SS400) and aluminum alloy (AA6082-T6). The number of meshes suitable for analysis is about 42,000. Fig. 7 shows the boundary condition for analysis and Von Mises stress distribution of an explorer robot's structure with rocker-bogie suspension. All components demonstrate that the maximum von Mises stress value does not exceed the yield strength of material. According to the simulation results, the maximum von-Mises stress value is 14.538 MPa, accompanied by a safety value factor of 16.852. Taking into account the highest von Mises stress level, it also shows that the rocker-bogie suspension doesn't go over the material's yield strength of 245 MPa (see Table 2). Moreover, the results of strength analysis suggest that the structure can sustain a maximum load of 2,479 N. The next step is to implement the final adjustments and prepare for production.

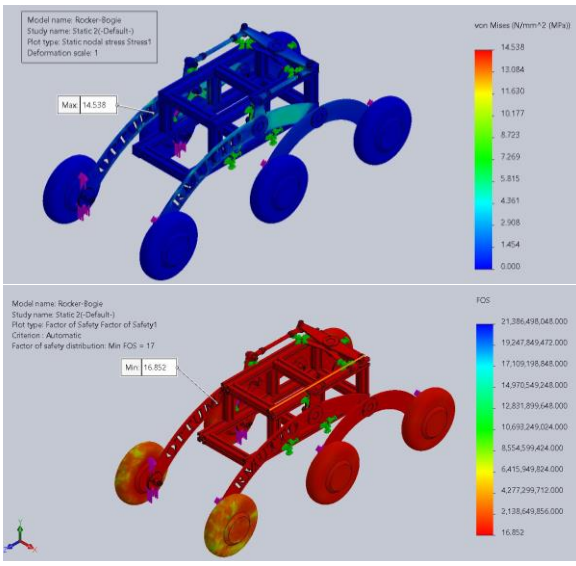

***Fig. 7*** *Von-mises stress and safety of factor*

## 2.3 Implementation

The structural components of the rocker-bogie suspension system and its sub-components are made up of SS400-grade steel, which is the most popular steel grade in Thailand today because of its use in general structures. SS400-grade steel is a type of hot rolled steel, as illustrated by its properties in Table 2. The rocker-bogie component is created using a laser-cut machine. The rocker has added its uniqueness and weight reduction to the structure, cutting the components into "RMUTTO". Furthermore, a 40 × 40 mm aluminum profile (Aluminum alloy AA6082-T6) forms part of the Explorer Robot's frame. It has special characteristics that are different from conventional metals, such as wear resistance and lightweight water, and can be assembled, cut, molded, drilled, and mounted according to the requirements of an explorer robots. The explorer robot, based on rocker-bogie suspension's study findings and design, has dimensions of 52, 100, and 37 cm, as well as a weight of 35.9 kg.

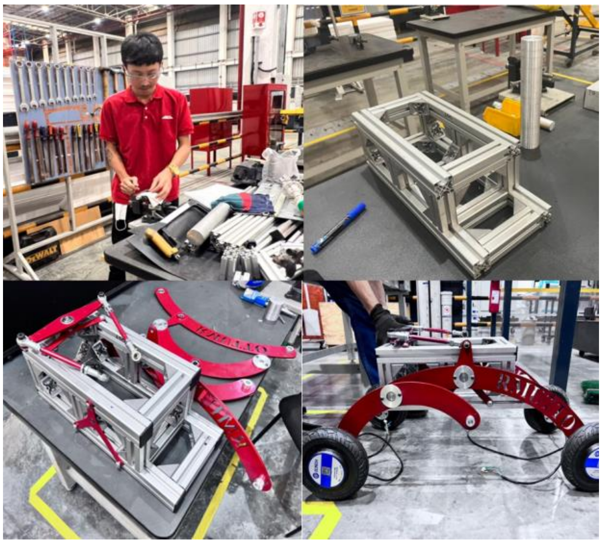

***Fig. 8*** *Implementation of explorer robot*

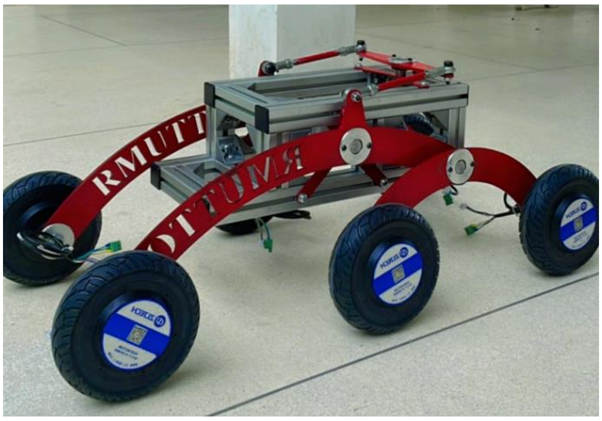

***Fig. 9*** *Prototype of an explorer robot by using rocker-bogie suspension*

### 2.4 Physical characteristics of movement

SolidWorks Motion used the motion analysis method to simulate the physical characteristics of movement during stair-climbing by exploration robots. We conducted the simulation using the SolidWorks program, taking into account the stairs' size, including the maximum step height and minimum tread width, as well as the motion analysis method. The Department of Civil Engineering and Urban Planning specifies that the steps should not be higher than 18 cm, and the horizontal part of the step should be at least 25 cm wide. After simulating the stair-climbing process in SolidWorks Motion, simulate the movement of the workpiece at the designated simulation location. The staircase measures 17 cm in height and 32 cm in width. The following section presents three cases: Case 1: Using the front wheels to climb the first step of the stairs. Case 2: climbing the steps. Case 2 is climbing the stairs on the middle pair of wheels, with the middle pair of wheels being on the second step of the stairs and the front wheels being on the third step of the stairs. Case 3: Climbing the stairs on the third step is climbing the stairs of the rear wheels; the rear wheels are on the first step, and the middle wheels are on the second step. The front wheels are on the third step. The front wheels are on the third step, making it the highest point of the stairs in this particular case.

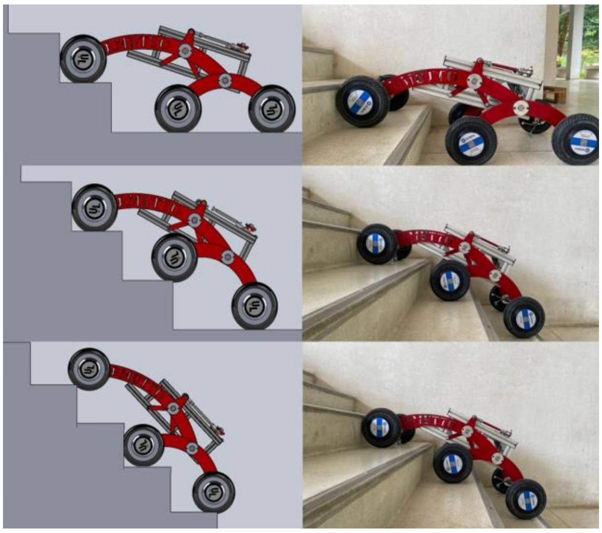

***Fig. 10*** *Physical characteristics of movement*

Testing the rocker-bogie movement of suspension while climbing a standard staircase Fig. 10 shown that this is a crucial component of its design. Such features may emerge during a site survey. So, a robotic survey is the most convenient and safe way. The simulation and testing results showed that the explorer robot can do well in all three cases and that the robots were able to successfully navigate stairs with varying characteristics.

## 3. DISCUSSION AND CONCLUSION

The study focuses on designing and implementing a rocker-bogie suspension system for an explorer robot using SolidWorks simulation. The design considers geometric parameters and mechanical components, ensuring accuracy in performance predictions. The researchers employ SolidWorks simulation and finite element analysis (FEA) to evaluate the strength of the suspension system under load conditions. The implementation stage involves creating a prototype of the explorer robot using rocker-bogie suspension, utilizing design and strength analysis to create a real work piece. Additionally, the study uses SolidWorks Motion to simulate the physical characteristics of stair-climbing by exploration robots, considering the specifications from the Department of Civil Engineering and Urban Planning. The design of explorer robot, with dimensions of 52, 100, and 37 cm, weighing 35.9 kg, has a maximum Von-Mises stress value of 14.538 MPa. The suspension design accommodates a maximum load of 2,479 N, retaining its original design features. The subsequent development step involves creating a motion control system to measure various operating environments, ensuring the robot operates as intended.

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