Journal of Engineering Mechanics and Machinery (2026)
Clausius Scientific Press, Canada

DOI: 10.23977/jemm.2026.110207
ISSN 2371-9133 Vol. 11 Num. 2

Development and Validation of a Finite Element Model for a Powered Two-Wheeler Based on GB 17761-2024

Lijuan He*, Haoxiong Yuan

School of Mechanical Engineering, Tianjin University of Science and Technology, Tianjin, China
**Corresponding Author*

Keywords: Powered Two-Wheeler; Finite Element Model; Geometric Parameterization; Structural Response Validation

Abstract: Powered two-wheelers are increasingly adopted for short- and medium-distance urban transport in China; the lightweight open structure demands accurate representation of geometry, mass distribution, connections, and deformation in collision simulations. This study developed and validated a high-fidelity FE model of a powered two-wheeler. A prototype meeting GB 17761-2024 was selected (mass 58 kg, wheelbase 1208.7 mm, height 1058.7 mm, width 387.9 mm, saddle height 808.7 mm). After importing the geometry into ANSA, geometry repair (364 defects corrected), simplification of non-critical components (brake details, wiring harnesses, lamp accessories, support brackets), meshing, connection definition, and material assignment were performed. The final model consisted of 104,217 nodes and 119,567 elements (102,332 quadrilateral shell, 3,183 triangular shell, 14,052 hexahedral solid). Material parameters were assigned based on component functions (frame, tires, pedals, saddle, fenders, battery, lamp cover). To validate the model, a drop-weight impact simulation of the frame and fork assembly was conducted per GB 17761-2024, with a 1 kg rigid roller mounted at the front-wheel position and a 22.5 kg drop weight released from 360 mm. No visible cracks or damage occurred; the wheelbase decreased from 1208.00 to 1202.57 mm (residual deformation 5.43 mm, far below the 40 mm limit). The developed FE model exhibits reasonable geometric accuracy, material definition, connections, and structural response, providing a reliable basis for collision simulation and test-scenario development.

1. Introduction

In recent years, the structure of urban travel demand in China has changed significantly. Traditional bicycles are limited by speed and riding efficiency, while motorcycles are constrained by safety concerns, emissions and traffic management requirements [1]. Although passenger cars provide higher safety and comfort, purchase and maintenance costs are relatively high, and increasing traffic congestion has weakened convenience in dense urban areas. Under these circumstances, powered two-wheelers have rapidly filled the gap between bicycles and passenger cars due to flexibility, low cost, low energy consumption, convenient operation and environmental friendliness [2]. Since the late 1990s, powered two-wheelers in China have entered a stage of rapid growth, driven by improvements in power system technology, low ownership cost and strong compatibility with short- and medium-distance travel demand. China has become the largest powered two-wheeler market in the world, with the current social ownership approaching 420 million units.[3]

The rapid popularization of powered two-wheelers has also brought increasingly serious traffic safety problems. In many urban road environments, powered two-wheelers often share traffic space with motor vehicles. Because the vehicle body is light and open, it cannot provide an enclosed protective space for the rider. Once a powered two-wheeler collides with a passenger car, the rider may directly contact the vehicle front structure, the ground or other road facilities. Therefore, powered two-wheeler crashes have become an important type of urban road traffic accident in China. Statistical data show that from 2020 to 2024, approximately 168,000 powered two-wheeler traffic accidents occurred in China, resulting in 21,899 fatalities. During this period, both the number of crashes and fatalities showed increasing trends, with the annual growth rates of accidents and deaths reaching 9.7% and 7.2%, respectively.[4]

At present, the assessment of powered two-wheeler rider protection is still insufficient in some crash safety evaluation systems. For example, the 2024 edition of C-NCAP has not yet fully covered the crash safety evaluation of two-wheeler riders. In contrast, international regulations and assessment methods such as GTR, Euro NCAP and J-NCAP have gradually incorporated protection requirements for vulnerable road users. Nevertheless, compared with pedestrian and cyclist safety, powered two-wheeler rider safety still lacks sufficient research on local anthropometric characteristics, typical accident scenarios and head protection requirements. Existing studies also show that accident reconstruction accuracy, rider posture definition, vehicle model fidelity and tissue-level biomechanical response remain key challenges in powered two-wheeler crash simulation. [5]

Numerical simulation provides an effective method for analyzing powered two-wheeler rider injury mechanisms. Multi-body models have high computational efficiency and are suitable for accident reconstruction and large-scale parametric analysis. However, ability to describe local deformation, structural failure and load transfer is limited. Finite element models can represent the geometric shape, material behavior, structural deformation and contact response of the powered two-wheeler in greater detail. In a vehicle-to-powered-two-wheeler collision, the powered two-wheeler is not only a means of transportation but also an important contact and load-transfer medium between the vehicle and the rider. The dimensions, stiffness, mass distribution, connections and deformation of the powered two-wheeler can influence the initial contact sequence, rider motion, load-transfer path and subsequent injury response.[6]

Therefore, it is necessary to develop a powered two-wheeler finite element model with clear geometric parameters, reasonable material definitions, reliable connection relationships and validated structural response. In this study, a representative powered two-wheeler conforming to GB 17761-2024 was selected as the modeling object. [7] The model was developed through geometry cleaning, mesh generation, component simplification, material assignment and connection modeling in ANSA, and was solved using LS-DYNA. A standard drop-weight impact simulation of the frame and fork assembly was conducted to verify the structural response of the developed model. [8]The objective of this study is to provide a reliable finite element model for subsequent powered two-wheeler rider coupling, accident reconstruction, injury mechanism analysis and protective equipment evaluation.

2. Prototype Selection and Geometric Parameters

The reliability of a powered two-wheeler finite element model first depends on whether the selected prototype has representative structural features and satisfies current regulatory requirements. In this study, a powered two-wheeler with high market ownership and representative structural characteristics was selected as the geometric prototype. The selected vehicle satisfies the core parameter requirements of GB 17761-2024, Safety Technical Specification for Electric Bicycles. The main geometric and mass parameters are listed in Table 1.

Table 1. Technical parameters of the powered two-wheeler prototype.

Parameter	Requirement of GB 17761-2024	Prototype value
Total mass	≤63 kg	58 kg
Overall height	≤1100 mm	1058.7 mm
Body width	≤450 mm	387.9 mm
Wheelbase	≤1250 mm	1208.7 mm
Saddle height	≥635 mm	808.7 mm

The selected prototype satisfies the standard requirements in terms of mass, height, width, wheelbase and saddle height. These parameters are also important for subsequent rider–vehicle coupling. The wheelbase determines the relative position of the front and rear axles, which affects vehicle attitude and load transfer during impact. The saddle height and handlebar position affect the initial riding posture and the relative contact relationship between the rider and the powered two-wheeler. The total mass and body width influence the inertial response and the spatial envelope of the vehicle during collision. Therefore, the selected prototype can provide a reasonable geometric and structural basis for powered two-wheeler crash simulation.

The geometric model retained the main external contour, assembly position and surface characteristics of the physical vehicle. The main components considered in the model included the frame, front fork, wheels, tires, saddle, pedals, fenders, battery components and other structures related to load transfer or rider contact. Small accessories with limited influence on the overall crash response were simplified or removed during preprocessing. This modeling strategy was adopted to balance geometric fidelity and computational efficiency.

3. Finite Element Model Development

3.1. Geometry Cleaning and Model Simplification

The powered two-wheeler geometric model was imported into ANSA for finite element preprocessing. After import, the model was mainly represented by surface structures. Although the geometric model retained the external contour and assembly relationship of the prototype, a large number of geometric defects were generated during format conversion and surface reconstruction. To accurately identify these defects, the TOOL-CHECK-GEOMETRY function in ANSA was used to conduct a batch inspection of the entire geometric model. A total of 364 geometric defects were identified.

The identified defects mainly included overlapping surfaces, small gaps, minor features and distorted surfaces. Overlapping surfaces were mainly distributed around the saddle contact surfaces and frame welded joints. Such defects may cause repeated mesh layers at the same location, resulting in initial penetration and abnormal contact force calculation. Small gaps were mainly located at component assembly interfaces, which could lead to mesh discontinuity and interruption of load-transfer paths. Minor features, such as small bolt-hole details, could significantly increase the number of elements and reduce the stable time step of explicit dynamic analysis. Distorted surfaces were mainly distributed in complex hub regions, which could cause meshing failure or severely distorted elements. These defects were repaired or deleted using the built-in geometry repair tools in ANSA.

After preliminary geometry repair, the MESH-FREE function was used for automatic mesh generation. Since the powered two-wheeler model contains many thin-walled and curved components, quadrilateral shell elements were used as the main element type. The basic mesh size of the full vehicle was set to 5 mm, the minimum element size was limited to 0.5 mm, and the upper limit of triangular shell elements was controlled at 5%. These settings were adopted to ensure both geometric adaptability and calculation stability.

In vehicle-to-powered-two-wheeler impact simulations, the key research objects are rider kinematics and biomechanical injury response. Some non-core vehicle components have little influence on the main load-transfer path but may significantly increase model complexity and computational cost. Therefore, parts such as detailed brake structures, wiring harnesses, front and rear lamp accessories, wire clips and support brackets were simplified or removed. The simplification retained the main structural components and contact-related regions, including the frame, fork, wheels, tires, saddle, pedals, battery-related parts and outer body components. This made the model more suitable for explicit dynamic crash simulation.

3.2. Mesh Generation and Element Statistics

After geometry cleaning and simplification, the powered two-wheeler model was remeshed and optimized. Shell elements were mainly used for thin-walled structures such as the frame cover, fenders, wheel-related components and outer panels. Solid elements were used for components requiring volumetric representation, including parts of the battery and other relatively thick structures. The connection relationships among the main components were defined using the CONSTRAINED-ND_R_BD command in ANSA, mainly at the joints between the frame, wheels and other assembled structures. This method ensured that the load could be transferred continuously between adjacent parts during impact simulation.

The final powered two-wheeler finite element model contained 104,217 nodes and 119,567 elements. The element composition is summarized in Table 2. Among the shell elements, 102,332 were quadrilateral shell elements and 3,183 were triangular shell elements. The proportion of triangular shell elements was approximately 3%, satisfying the mesh-quality requirement. In addition, the model contained 14,052 hexahedral solid elements. The element statistics indicate that the model was mainly composed of quadrilateral shell elements, which is suitable for thin-walled vehicle structures and explicit dynamic impact analysis.

Table 2. Element statistics of the powered two-wheeler finite element model

Item	Number
Nodes	104,217
Total elements	119,567
Quadrilateral shell elements	102,332
Triangular shell elements	3,183
Ratio of triangular shell elements in shell elements	3%
Hexahedral solid elements	14,052

The use of quadrilateral shell elements as the dominant element type improved the bending and torsional response representation of thin-walled components. The controlled number of triangular shell elements reduced the risk of numerical instability and local mesh distortion. The hexahedral solid elements provided volumetric representation for relatively thick components. Overall, the mesh strategy satisfied the requirements of model accuracy, contact stability and computational efficiency.

3.3. Material Definition

Material properties were assigned according to the structural function and material type of each component. In LS-DYNA, different material models were selected to represent the mechanical behavior of the powered two-wheeler components. The frame was modeled as Q235 steel using MAT3, reflecting its main load-bearing function. The tires were modeled as rubber using MAT27.

The pedals and fenders were modeled using plastic materials, and the saddle was modeled using polyurethane foam. Battery-related components were simplified and assigned representative material parameters for lithium iron phosphate and carbon. The lamp cover was modeled as plastic. The detailed material parameters are listed in Table 3.

Table 3. Material parameters of the powered two-wheeler finite element model

Component	Material	LS-DYNA material model	Density (kg/m^3)	Young’s modulus (MPa)	Poisson’s ratio
Frame	Q235 steel	MAT3	7850	210000	0.30
Tire	Rubber	MAT27	1750	300	0.30
Pedal	ABS plastic	MAT24	1190	7000	0.30
Saddle	Polyurethane foam	MAT57	65	0.2	0.25
Fender	Polypropylene plastic	MAT24	920	1200	0.30
Battery positive electrode	Lithium iron phosphate	MAT1	2300	50000	0.30
Battery negative electrode	Carbon	MAT1	1700	20000	0.25
Lamp cover	Plastic	MAT24	2950	2000	0.30

Finally, the powered two-wheeler finite element model was counted. The total number of nodes was 104,217, and the total number of elements was 119,567. Among them, there were 102,332 quadrilateral shell elements and 3,183 triangular shell elements. The number of triangular shell elements accounted for 3% of the total number of shell elements, satisfying the mesh-quality requirement. In addition, the model contained 14,052 hexahedral solid elements. At this point, the powered two-wheeler finite element model was completely developed. The development process is shown in Figure. 1.

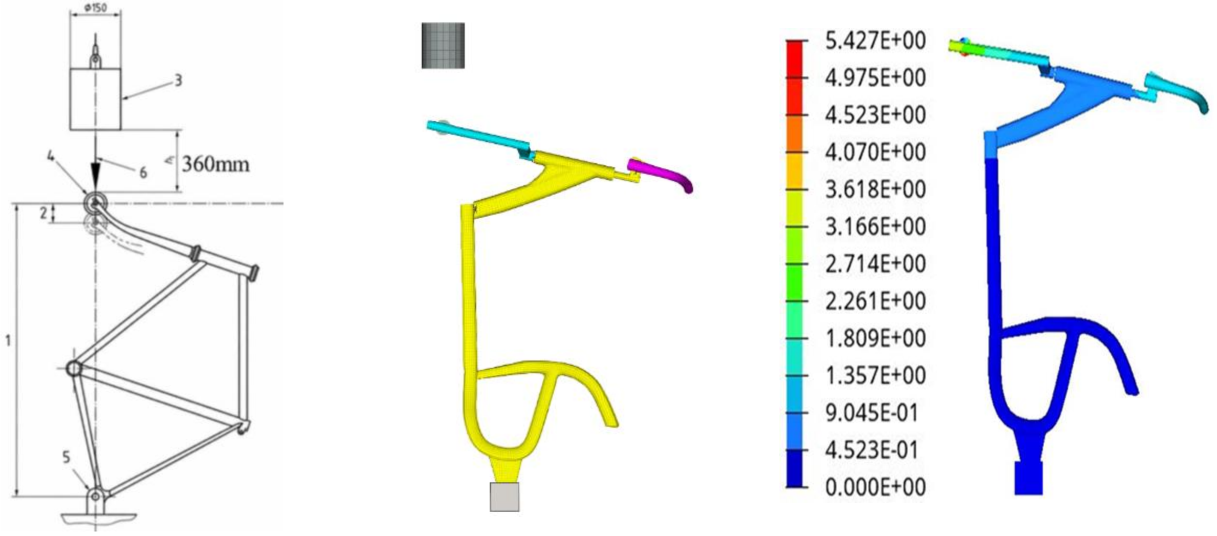
(a) (b) (c)

Figure. 1 Development process of the powered two-wheeler finite element model: (a) Physical model; (b) geometric model; (c) finite element model

4. Validation Method Based on GB 17761-2024

GB 17761-2024, Safety Technical Specification for Electric Bicycles, is the mandatory national standard for the production, inspection and compliance determination of electric bicycles in China. The standard clearly specifies the validation method and pass/fail criteria for the impact test of the frame or fork assembly. This test can comprehensively evaluate the impact resistance, stiffness characteristics and structural integrity of the frame structure, and is an effective method for validating the mechanical performance of powered two-wheelers. Based on the requirements of GB 17761-2024, a simulation test scenario was established. The structural mechanical response accuracy of the developed powered two-wheeler finite element model was validated through a drop-weight impact simulation test, thereby completing the validity verification of the model.

In GB 17761-2024, for the drop-weight impact test of the frame or fork assembly, the test specimen is a completely assembled frame and fork assembly, including the frame body, front fork, front and rear wheel axles and other core load-bearing structures. The test bench is a high-stiffness rigid supporting structure and does not deform or displace during the test. The rear axle of the frame is completely fixed on the rigid support of the test bench. A lightweight roller with a diameter of no more than 55 mm is installed at the front-wheel mounting position of the fork, and the total mass of the roller should be no more than 1 kg. A standard cylindrical solid drop weight with a total mass of 22.5 kg is used. The impact surface of the drop weight is a flat rigid plane and remains parallel to the upper surface of the roller. The vertical distance between the two is defined as the drop height. The drop weight falls freely from a height of 360 mm, ensuring that it vertically impacts the center of the roller and avoiding load-distribution distortion caused by eccentric impact. The regulatory test is shown in Figure. 2 (a).



(a) (b) (c)

Figure 2 Frame impact strength test(falling hammer)(a) Regulatory test;(b) simulation test; (c) deformation response

After the impact test is completed, the frame and fork assembly should have no visible cracks or damage. The permanent deformation of the distance between the centerlines of the two wheel axles, namely the wheelbase, should be less than or equal to 40 mm after impact. The test can be judged as qualified only when both requirements are satisfied, which means that the powered two-wheeler finite element model is validated.

At the front-wheel mounting position of the fork, a rigid roller model with a mass of 1 kg was established, and the roller was connected to the fork through nodal rigid constraints. A rigid drop weight with a mass of 22.5 kg finite element model was established using the MAT20-RIGID rigid-body constitutive model in LS-DYNA to ensure that the drop weight did not deform during the impact process. The impact surface of the drop weight was set parallel to the upper surface of the roller, and the initial vertical distance was set to 360 mm to simulate the free-fall process of the drop weight. The simulation test is shown in Figure. 2 (b).

After the simulation calculation was completed, the dynamic response, structural deformation and final test results during the entire impact test process were comprehensively analyzed. The results showed that no visible cracks or damage appeared in the assembly. The initial wheelbase of the frame before impact was measured as 1208 mm. After the impact stabilized, the wheelbase of the frame was 1202.57 mm. The calculated residual deformation of the wheelbase was 5.43 mm, which was smaller than the 40 mm limit specified in the standard and met the mandatory pass requirement of the national standard. Therefore, the effectiveness of the established powered two-wheeler finite element model was verified. The deformation response is shown in Figure. 2 (c).

5. Discussion

The principal characteristic of the present model lies in the fact that it was developed on the basis of a representative powered two-wheeler prototype that conforms to the main technical requirements of GB 17761-2024. Compared with simplified rigid models or purely geometric representations, the developed finite element model is capable of representing not only the external geometric features of the powered two-wheeler, but also its material properties, structural connections and deformation response under impact loading. This capability is of particular importance because, during vehicle-to-powered-two-wheeler collisions, the powered two-wheeler is not merely involved as a moving object, but also functions as an important contact and load-transfer structure. Accordingly, parameters such as wheelbase, saddle height, body width, frame stiffness and component connection relationships may influence the initial contact sequence, structural deformation pattern and load-transfer path in crash simulations.

From the perspective of finite element preprocessing, a systematic modeling procedure was adopted, in which geometry inspection, defect repair, simplification of non-critical components, mesh generation, material assignment and connection definition were successively performed. During geometry inspection, 364 geometric defects were identified and corrected, thereby reducing the possibility of repeated mesh layers, discontinuous boundaries, severely distorted elements and abnormal contact-force calculation. Meanwhile, a basic mesh size of 5 mm and a minimum element size of 0.5 mm were used, so that sufficient geometric resolution could be achieved while the computational cost was kept within an acceptable range. The final model contained 119,567 elements, and triangular shell elements accounted for only approximately 3% of the total shell elements, indicating that the mesh quality was acceptable for explicit dynamic impact analysis.

With respect to material modeling, different material models and parameters were assigned according to the structural functions of individual components. The main load-bearing frame was modeled as Q235 steel, whereas the tires, pedals, saddle, fenders, battery components and lamp cover were defined using material properties corresponding to their respective mechanical roles. Compared with the use of a single homogeneous material for the entire vehicle, this component-dependent material definition strategy allows differences in stiffness, density and deformation behavior among various structural parts to be more reasonably represented. As a result, the mass distribution and load-transfer characteristics of the powered two-wheeler can be described in a more physically meaningful manner during impact simulation.

The validation conducted according to GB 17761-2024 provides an essential basis for evaluating the structural response reliability of the developed powered two-wheeler finite element model. In the drop-weight impact simulation of the frame and fork assembly, the residual wheelbase deformation was calculated to be 5.43 mm, which was significantly lower than the allowable limit of 40 mm specified in the standard. In addition, no visible cracks or structural damage were observed after impact. These results indicate that the frame and fork assembly of the developed model exhibits satisfactory impact resistance and load-transfer stability under the prescribed standard impact condition, and that the adopted modeling strategy, including geometric simplification, mesh generation, connection treatment and material assignment, is generally reasonable.

Nevertheless, several limitations should also be acknowledged. First, the validation was mainly performed at the level of the frame and fork assembly, whereas independent component-level validation tests for tires, saddle, pedals, battery assembly and handlebar were not included. Second, the material parameters were mainly assigned according to typical component materials and the requirements of crash simulation; therefore, further calibration based on physical material tests or component-level impact tests would be beneficial for improving the accuracy of local deformation prediction. Third, the present validation was focused on a standard drop-weight impact condition, and the applicability of the model under more complex crash boundary conditions still requires further investigation. In future studies, the developed powered two-wheeler finite element model should be further evaluated through full vehicle-to-powered-two-wheeler collision simulations and real-world accident reconstructions, so that its reliability in predicting vehicle structural deformation, contact response and load-transfer behavior can be more comprehensively verified.

6. Conclusions

In this study, a high-fidelity finite element model of a powered two-wheeler was developed and validated, with the aim of providing a reliable digital vehicle model for crash simulation and structural response analysis. The main conclusions can be summarized as follows.

(1) A representative powered two-wheeler satisfying the main technical requirements of GB 17761-2024 was selected as the prototype for model development. The total mass, overall height, body width, wheelbase and saddle height of the selected prototype were 58 kg, 1058.7 mm, 387.9 mm, 1208.7 mm and 808.7 mm, respectively, all of which complied with the corresponding limits or requirements specified in the standard.

(2) The finite element model was established in ANSA through a systematic preprocessing procedure, in which geometry cleaning, component simplification, mesh generation, connection definition and material assignment were successively performed. During geometry inspection, 364 geometric defects were identified and corrected, and non-critical components were simplified while the main load-bearing and contact-related structures were retained, thereby improving computational efficiency without sacrificing the essential structural characteristics of the powered two-wheeler.

(3) The final powered two-wheeler finite element model consisted of 104,217 nodes and 119,567 elements, including 102,332 quadrilateral shell elements, 3,183 triangular shell elements and 14,052 hexahedral solid elements. Since triangular shell elements accounted for only approximately 3% of the total shell elements, the mesh quality was considered acceptable for explicit dynamic impact analysis.

(4) Material parameters were assigned according to the structural functions and mechanical characteristics of different components. The frame, tires, pedals, saddle, fenders, battery components and lamp cover were modeled using appropriate LS-DYNA material models, so that the stiffness distribution, mass characteristics and deformation behavior of the powered two-wheeler could be represented in a more physically reasonable manner.

(5) A drop-weight impact simulation of the frame and fork assembly was carried out in accordance with GB 17761-2024. In the validation simulation, A rigid drop weight with a mass of 22.5 kg was released from a height of 360 mm and impacted a 1 kg roller installed at the front-wheel mounting position. No visible crack or structural damage was observed after impact. The wheelbase was reduced from 1208.00 mm to 1202.57 mm, corresponding to a residual deformation of 5.43 mm, which was far below the allowable limit of 40 mm specified in the standard.

(6) The developed powered two-wheeler finite element model was shown to have reasonable geometric accuracy, mesh quality, material definition and structural response. Therefore, it can be

used as a reliable digital vehicle model for powered two-wheeler collision simulation, vehicle structural response analysis, accident reconstruction and standardized test-scenario development.

References

[1] Cherry C, Cervero R. Use characteristics and mode choice behavior of electric bike users in China[J]. Transport Policy, 2007, 14(3): 247-257.
[2] Weinert J, Ma C, Cherry C. The transition to electric bikes in China: history and key reasons for rapid growth[J]. Transportation, 2007, 34(3): 301-318.
[3] Shanghai iResearch Market Consulting Co., Ltd. White Paper on China's Two-Wheeled Electric Vehicle Industry in 2025[R]. Shanghai: Shanghai iResearch Market Consulting Co., Ltd., 2025: 269-325.
[4] National Bureau of Statistics. China Statistical Yearbook[M]. Beijing: China Statistics Press, 2025.
[5] Ye F, Wang C, Cheng W, et al. Exploring factors associated with cyclist injury severity in vehicle-electric bicycle crashes based on a random parameter logit model[J]. Journal of Advanced Transportation, 2021(1): 5563704.
[6] Hu L, Hu X, Wang J, et al. Casualty risk of e-bike rider struck by passenger vehicle using China in-depth accident data[J]. Traffic Injury Prevention, 2020, 21(4): 283-287.
[7] GB 17761-2024. Safety Technical Specification for Electric Bicycles [S]. Beijing: Standards Press of China, 2024.
[8] Wang W T, Wu Z H. Modal analysis of automobile wheel hub based on ANSA[J]. Internal Combustion Engine and Powerplant, 2025, 42(3): 78-82.