Seismic Performance of Building Structures Using Structural Integral Mechanics Model under the Guidance of Fluid Mechanics

Jing liu[1,] * and Gaochao Wang[2]

[1]Huanghe Science and Technology College, Zijingshan South Road 666, Zhengzhou, 450000, China

[2]Zhuyou Zhizao Architectural Design Co., Ltd., Weisi Road 19, Zhengzhou, 450000, China

* Corresponding Author Email: liujing988412@163.com

Abstract. The purpose is to study the core causes of serious collapse of buildings damaged in the earthquake and improve the seismic performance of buildings to reduce casualties. First, the theoretical overview of seismic engineering and related form and requirements of the building structure are deeply studied. Next, the building node structure is deeply analyzed according to the knowledge of fluid mechanics and the basic idea of the finite element method of integral structure. The seismic performance of building structures and the principles and requirements of seismic engineering are analyzed and summarized. It is found that the concrete analysis and description of seismic performance in the research method of fluid mechanics is a steel structure's bending resistance, deformation and displacement degree, and the bearing degree of external impact force. Further, the model design of the integral structure is carried out through the finite element idea of fluid mechanics. Then, the model simulation experiment is conducted to obtain the curve of the impact force on the building structure, the ultimate bearing capacity of the steel beam joint and the skeleton displacement under the impact. Meanwhile, the degradation of stiffness and strength of node structure during an earthquake is analyzed. Finally, through the simulation results, it is concluded that the maximum displacement between node members under the action of impact force is no more than 300mm, so the model has high impact bearing capacity and strong seismic capacity, and can meet the requirements of seismic fortification. This exploration will be of great significance to the development of building seismic engineering under the guidance of fluid mechanics.

Keywords: fluid mechanics; structural integral mechanics; finite element method; building seismic structure; mechanical property.

1. Introduction

The ground vibration caused by the earthquake is called ground motion. The extreme ground motion will cause house collapse, mountain collapse, and ground crack and greatly harm human life and property. Since the 20th century, the total number of deaths from earthquakes in the world has been nearly 1.2 million. The death toll caused by various natural disasters is increasing year by year, and the death toll caused by earthquakes accounts for most of the casualties of natural disasters. There are countless earthquakes in various countries and regions. 41% land, 50% cities and 70% of the large and medium-sized cities with more than one million people are in high-intensity areas with an earthquake intensity of 7 or more [1]. It reveals that the serious earthquake disaster is one of the great tests for the world.

Recently, worldwide earthquake disasters have caused heavy casualties and almost consistent destruction. In addition to the objective factors such as the large scale and high magnitude of the earthquake, it is mainly because the buildings where human beings are located have not undergone good seismic engineering design. Moreover, these houses usually collapse into piles of stones and building materials after violent vibration, and human beings will be buried alive. Such cruel scenes are very similar in disasters and earthquakes with a death toll of more than 20000 [2]. According to the classified statistics of more than 130 earthquake disasters with large casualties in the world, more than 95% of the casualties are caused by the destruction and collapse of buildings and structures. In

the 1920s, earthquake resistance began to become an engineering science. In the static design method at that time, the seismic inertia force borne by the structure was expressed as the product of the structure mass and the ground motion acceleration. In order to determine the seismic load, people have been looking for the corresponding relationship between intensity and acceleration. Therefore, the early structural seismic theory is basically based on static analysis. In 1941, some scholars introduced the concept of response spectrum into earthquake engineering. On this basis, a systematic response spectrum theory was established in 1953 and was further improved by many scholars. The global engineering and structural engineering circles have carried out the following work on the seismic design theory based on structural performance: grade III structural performance level, grade III seismic fortification level, structural calculation and analysis method and structural safety. At present, some achievements have been obtained through a lot of research, such as seismic design based on structural performance, emphasizing structural displacement behavior and nonlinear elastoplastic static analysis, and the basic equations of fluid mechanics and solid mechanics, and listing the boundary conditions involved in numerical calculation. The present research has clarified the dynamic conditions that seismic building structural joints need to meet.

Too serious earthquakes will lead to large-area casualties, serious damage and even collapse of all kinds of buildings and high-rise structures. Building earthquake-resistant buildings that can withstand strong earthquakes is the most direct and effective method to reduce earthquake disasters [3]. Therefore, the key to avoiding casualties is to carry out corresponding seismic fortification of various buildings so that they will not be damaged or collapsed in destructive earthquakes. First, the form and specification requirements of seismic engineering and building structure are studied and analyzed. Then, according to the relevant theoretical concepts of fluid mechanics, the idea of overall structure and finite element method, the building structure is deeply analyzed. Then, the principles of building seismic performance and seismic engineering are sorted and summarized. It is found that the seismic performance of building structure can be reflected by the bending resistance, deformation and displacement of steel structure when it resists impact force. Next, the building structure is simulated by fluid mechanics theory and finite element method. Finally, through the model simulation experiment, the impact force curve of the building structure in the earthquake, the bearing capacity limit of the steel beam joint, the skeleton displacement under the impact, the stiffness and strength degradation of the building's joint material in the epicenter are simulated. The research innovation is to give the basic equations of fluid mechanics and solid mechanics, list the boundary conditions involved in the numerical calculation, and then clarify the dynamic conditions that architectural structural joints need to meet. Finally, the finite element solution of the basic variable equation is conducted. This exploration will be of great significance to the development of building seismic engineering.

2. Related theories of structural integral mechanics and seismic model design of building structures

2.1 Overview of seismic engineering theory and building structure forms and requirements

There are generally two kinds of anti-seismic measures, namely civil air-defense construction and seismic engineering [4]. Civil air-defense construction is a project with civil air defense function. Civil buildings are reflected in concealed shelters, three defenses, ventilation and filtration, and temporary living facilities, focusing on air defense, poison prevention, explosion prevention, personnel avoidance and other functions. Enough daily necessities are also required. However, seismic engineering mainly focuses on the robustness of the structure itself, which is a way to alleviate earthquake damage in essence. Moreover, the convenience of the shock absorption channel included in building seismic engineering is also critical.

Seismic engineering is a subject and a technology, which involves various fields of engineering seismic. It includes seismic ground motion characteristics, random process description of ground motion, seismic zoning, site-related seismic design response spectrum and engineering application.

It also includes the theoretical basis and practical methods of structural seismic response analysis, in which the principle of structural dynamics, linear and nonlinear seismic response and structural random vibration analysis are all seismic research methods. The seismic design method and seismic reinforcement technology are also included. This section is to analyze the principles of seismic design. The theoretical and experimental research results of the aseismic capacity of various structures are comprehensively introduced, including conceptual design of masonry, reinforced concrete and steel structure, seismic checking and structural measures [5]. Figure 1 displays the basic principles and requirements of seismic design.

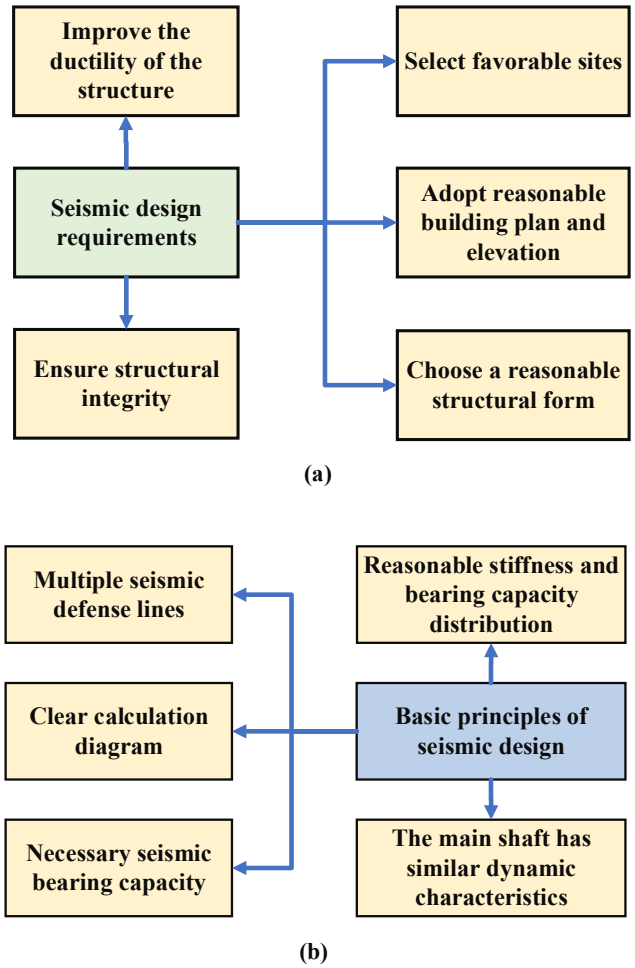

Figure 1. basic principles and requirements of seismic design (a: seismic design requirements; b: seismic design principles)

Figure 1a reveals multiple requirements for seismic design [6]. The site is the first requirement, and a detailed investigation should be conducted to avoid sections unfavorable to building earthquake resistance. The general location is in hard or medium-hard sites to effectively reduce the earthquake's impact on buildings. Reasonable building plane and elevation can make the layout more in line with earthquake resistance requirements to make the building have better earthquake resistance. Generally, the simple and symmetrical plane and elevation are selected to make the vibration transmission path clear. The structural form of buildings is also particularly important, including multiple factors such as seismic fortification intensity, height, site, economy and materials, which need to be determined through careful investigation and analysis. Structural ductility is also a requirement that cannot be ignored, that is, the displacement and deformation of the internal structure of the building after vibration. Good ductility can effectively buffer the earthquake. Meanwhile, there are structural integrity requirements. As the name suggests, the structure is a whole composed of many units, which plays an anti-seismic role through coordinated work. Therefore, if the structure loses its integrity, the

construction of each link cannot play its seismic role normally, which is easy to cause the overall collapse. In addition to the above requirements, the seismic design should also meet five principles in Figure 1b [7]. They are a clear calculation diagram, multiple seismic defense lines, necessary anti-seismic bearing capacity, reasonable stiffness and bearing capacity distribution, and the main shaft similar to the dynamic characteristics. Only in this way can each component's seismic capacity be fully played to ensure the integrity and continuity of the structure.

2.2 Knowledge of fluid mechanics and the basic idea of integral structure finite element method

Based on the knowledge of fluid mechanics and the basic idea of the finite element method of integral structure, the building node structure is deeply analyzed to determine its seismic performance. Fluid mechanics belongs to mechanics. Its main research content is the state under the action of force and the interaction force and law between nodes. It contains six basic assumptions. Figure 2 shows the specific assumptions.

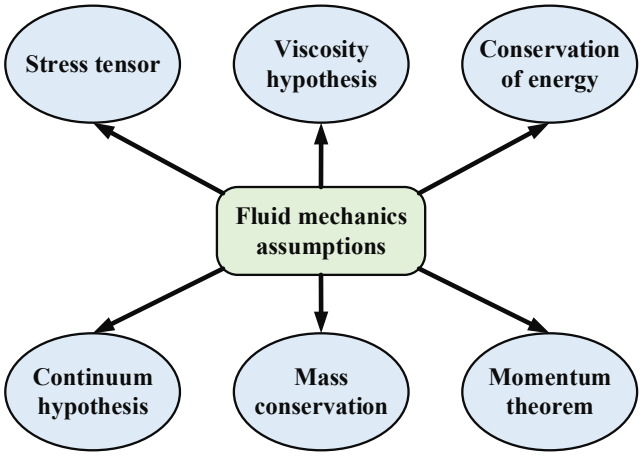

Figure 2. basic assumptions of fluid mechanics

The assumptions in Figure 2 have evidence. The continuum assumption comes from that matter is composed of molecules, although the molecules are discrete and make irregular thermal motion. Fluid mechanics assumes that all fluids meet the following assumptions: mass conservation, momentum conservation and continuum assumption. In fluid mechanics, it is often assumed that the fluid is incompressible, that is, the density of the fluid is a certain value. Liquid can be regarded as an incompressible fluid, while gas is not. Sometimes, it is assumed that the fluid's viscosity is zero, and the fluid is non-viscous. Gases are often regarded as inviscid fluids. If the fluid's viscosity is not zero and the fluid is surrounded by a container (such as a pipe), the velocity of the fluid at the boundary is zero. The statistical average value of fluid molecular micelle in thermal motion is stable in a quite small range [8]. Hence, it can be approximately considered that the fluid is composed of continuous substances, in which the physical quantities such as temperature, density and pressure are scalar fields with continuous distribution. The purpose of mass conservation is to establish equations describing fluid motion. Specifically, the mass flowing into any closed surface in the absolute coordinate system is equal to the mass flowing out of the surface. The change rate of the material derivative of the mass of the fluid micelle with time is zero. Fluid mechanics belongs to the category of classical mechanics, so theorem of momentum and theorem of the moment of momentum are applicable to fluid micelle. Fluid micelles are only affected by surface forces. In the non-isotropic fluid, the position of the fluid micelle is different, and the surface's normal direction is different, so the stress is different. The stress is described by the inner product of a second-order tensor and the normal direction of the surface. Only three quantities of the second-order stress tensor are independent. Therefore, as long as the stress on three different surfaces of a point is known, the stress distribution of this point can be determined

[9]. The fluid is viscous, and the stress tensor can be derived by using the viscosity theorem. The work done by the volume force on the fluid micelle in unit time plus the product of the surface force and the deformation velocity of the fluid micelle is equal to the internal energy increment of the fluid micelle in unit time plus the kinetic energy increment of the fluid micelle. Figure 3 shows the research method.

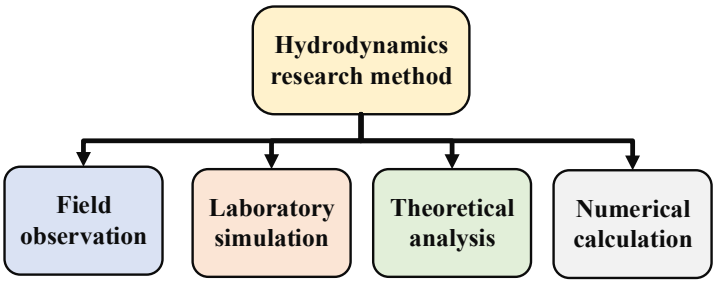

Figure 3. research methods of fluid mechanics

Streamline is divided into horizontal and longitudinal. Horizontal is generally various necessary or existing paths, which are usually directly related to the functional layout [10]. The longitudinal is generally a traffic space such as stairs and elevators. A relatively reasonable plane can be obtained by arranging these horizontal and longitudinal elements. However, different streamlines will lead to different space combinations that will produce different architectural forms and space atmospheres. Based on different spatial forms and atmospheres, different materials and formal languages should be selected to enhance the experience brought by spatial forms and atmospheres [11]. Therefore, what kind of streamline to choose and how to create space experience under different streamlines have become two major problems that need to be explored and tried. Figure 4 is a diagram of streamline description.

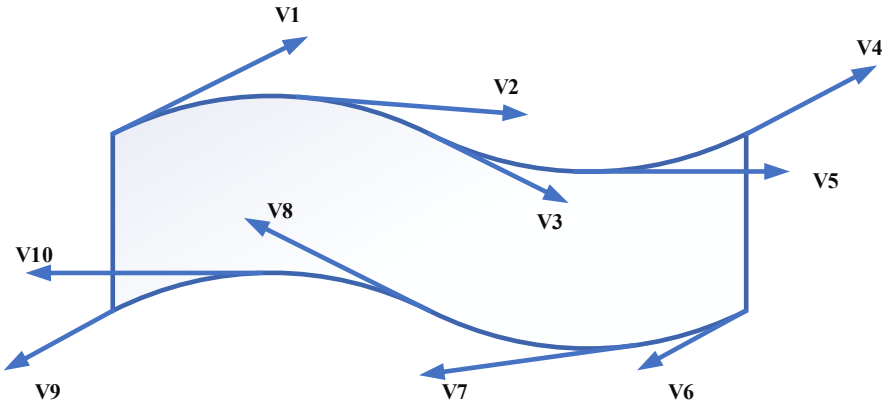

Figure 4. description of streamline

The streamline description in Figure 4 clearly shows that as long as it is a point on the bending curve, the outer streamline does not intersect. In this way, the contact points constructed by each node in the building can be regarded as particles with different positions [12]. The dynamics of each building component can be regarded as a smooth curve, so it can be easily solved to describe the motion of the internal structure of the building when it is vibrated.

The basic idea of the finite element method is to solve the extreme value of the function based on its own discrete theory and method. Its essence is to transform the continuous-discrete mode into a combination of a group of units. Each combination contains a corresponding function to represent the unknown function. Through the numerical interpolation of the corresponding function on each unit node, an infinite degree of freedom problem is simplified into a single finite degree of freedom problem. Figure 5 displays the finite element setting and setting of the degree of freedom.

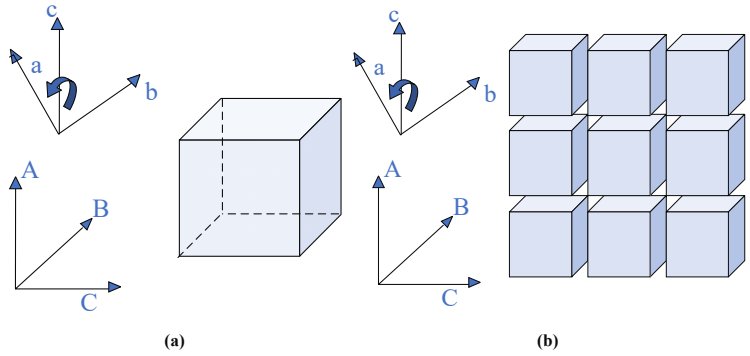

Figure 5. finite element setting and degree of freedom setting (a: finite element and degree of freedom; b overall structure diagram)

Figure 5 shows that the region requiring a solution is first discretely divided into a finite set of elements. The elements can be divided into any desired shape in the segmentation process. Of course, in solving two-dimensional problems, triangular or three-dimensional element sets and rectangular element sets are generally used [13]. For three-dimensional space problems, tetrahedrons and polyhedrons can be adopted. Besides, each element vertex in the element set divided into desired shapes is collectively referred to as node [14]. The functions on shaped discrete meshes are used to perform function interpolation on the set of partition units to generate a linearly finite function [15]. Through the set of these element functions, the field function of the whole continuum can be approximately reflected. Then, the unknown function equations can be established by using the energy equation. Finally, the numerical value of the finite element method can be obtained.

2.3 Overall structure scheme and model design of building under the guidance of fluid mechanics

At present, the global buildings are mainly high-rise buildings, and their main structural systems include frame, shear wall, framed shear wall, and tube structure. According to the functions and characteristics of high-rise buildings, the structure is designed layer by layer [16]. Figure 6 shows the structural design of a high-rise building.



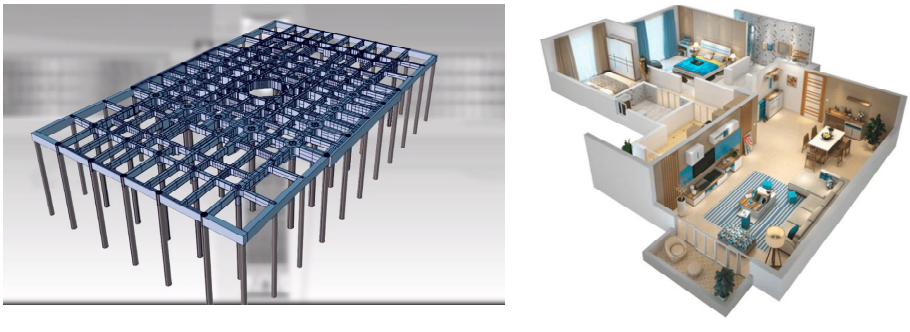

Figure 6. structure of high-rise building (a: steel beam node diagram; b: steel frame structure diagram; c: layout stereoscopic diagram)

After the model is established, the calculation is conducted according to the relevant regulations, the steel pipe material in actual application and the concrete strength in the experiment [17]. The calculation of shaft bearing pressure value of the tubular column is:

$$N_\rho=f_sA_s \tag{1}$$

N_ρ is the shaft bearing pressure value of the tubular column, f_s is the yield strength of the steel pipe, and A_s is the variance value of the steel pipe column. When the beam-column joint is subjected to impact force, the deformation at yield needs to be considered in addition to displacement and deformation [18]. For the convenience of research, the displacement ductility is analyzed and calculated, that is, the ratio between deformation degree and yield deformation is calculated by equation. A large ductility means that the impact resistance is good. On the contrary, it indicates poor resistance [19]. The calculation of displacement ductility reads:

$$m=\frac{\Delta x}{\Delta y} \tag{2}$$

The difference Δx of x is the shape variable, while the difference Δy of y is the shape variable at yield. m is the displacement ductility.

The calculation equations of the cross-section resistance bending rigidity value of the steel pipe column and the resistance bending rigidity value of the steel beam are the same. It is:

$$EI=E_sI_s \tag{3}$$

EI is the bending rigidity of concrete-filled steel tubes [20]. E_s is the elastic modulus, and I_s is one-twelfth of the side length of the steel pipe column to the fourth power.

The calculation of bending resistance capacity of steel beam reads:

$$M_{uk}=[0.5A_s(h-2t-d_n)+bt(t+d_n)]f_y \tag{4}$$

$$d_k=\frac{(1-\beta)\varepsilon^{in}E_0}{\alpha_k+(1-\beta)\varepsilon^{in}E_0} \tag{5}$$

$$F_{EK}=\alpha G \tag{6}$$

A_s is the area of longitudinal steel bar, h is the beam height, b is the beam width, f_y is the bending strength, and d_n is the bending rigidity. β is the proportional coefficient of plastic strain and unelastic strain, and the parameter k is 0.667.

The performance indexes of steel are generally divided into mechanical properties, chemical properties and process properties. Mechanical properties refer to the resistance of metal materials to chemical or electrochemical reactions when they are in contact with the surrounding medium. Strength refers to the ability of a material to resist deformation or fracture. There are two kinds: yield strength and tensile strength. Strength index is an important index to measure structural steel. The higher the strength is, the greater the force (also known as load) borne by the steel is. Hardness refers to the ability of the material surface to resist the pressure of hard objects. There are three common types: Brinell hardness, Rockwell hardness and Vickers hardness. Hardness is an index to measure the surface deformation ability of steel. The higher the hardness is, the better the wear resistance of steel is, that is, it is not easy to wear. Plasticity refers to the ability of a material to deform without breaking. There are two expression methods: elongation and section shrinkage. Plasticity is an index to measure the forming ability of steel. The higher the plasticity is, the better the ductility of steel is, that is, it is easy to draw or roll. Toughness, also known as impact toughness, refers to the ability of a material to resist impact deformation, expressed as impact value. Impact toughness is an index to measure the impact resistance of steel. The higher the value is, the stronger the ability of steel to resist moving load is. Table 1 shows the shaft bearing pressure value of the tubular columns, cross-section bending rigidity value, bending resistance bearing capacity value and bending resistance stiffness value.

Table 1. performance values of steel

Parameter type	Concrete filled steel tube	Steel pipe column	Concrete filled steel tubular beam	Steel beam
Shaft bearing pressure value of the tubular columns (KN)	357.0	369.9	\	\
Cross-section bending rigidity value ($N \cdot mm^2$)			\	\
Bending resistance bearing capacity value (kN·m)	\	\	129	121.0
Bending resistance stiffness value ($N \cdot mm^2$)	\	\		

The impact force set in the experiment is to apply an impact force along the direction of the steel column on the top of the steel column model, and gradually increase the impact force value until the test joint is damaged. The stress distribution, local deformation and impact load limit are analyzed through the simulation results [21]. In the impact experiment, a lot of investigations and sampling are carried out before the simulation experiment due to the need to preset a force or equation. The collected data show that the impact force does not increase linearly [22]. An experimental parameter curve can be simulated for the four-stage stress of the actual building under impact. Figure 7 is the simulation curve of impact force.

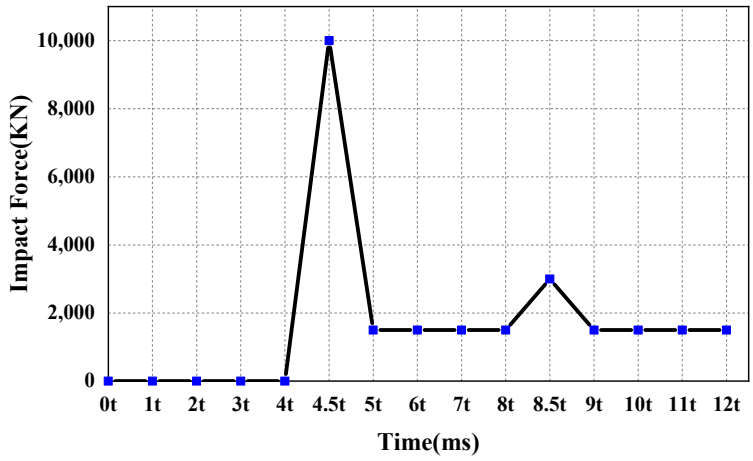

Figure 7. impact force simulation curve

Figure 7 suggests that the impact force setting in the model is subdivided into four stages, and each stage is linearly distributed. It is set as no impact force at 0t-4t. The first stage action time is set to 4t-5t, the second stage action time is set to 5t-8t, the third stage action time is set to 8t-9t, and the fourth stage action time is set to 9t-12t. The corresponding value at 4.5t is set as the limit value of impact force in the first stage. The corresponding value at 8.5t is set as the limit value of the third stage. Such a simulation setting can restore the change of real impact load to the greatest extent.

3. Experimental results and analysis

The simulation experiment of the seismic model of the building structure is conducted based on the idea of finite element of fluid mechanics, the impact force curve of the building structure. Then, the bearing capacity limit of steel beam joints and the skeleton displacement under impact can be obtained. Meanwhile, the degradation of stiffness and strength of node structure during an earthquake is analyzed to verify the model's effectiveness.

3.1 Analysis of bearing limit of impact force of building structure

A unidirectional downward impact force is applied at the top. Figure 8 shows the impact force curve of the building structure and the simulation results of the bearing capacity limit of steel beam joints.

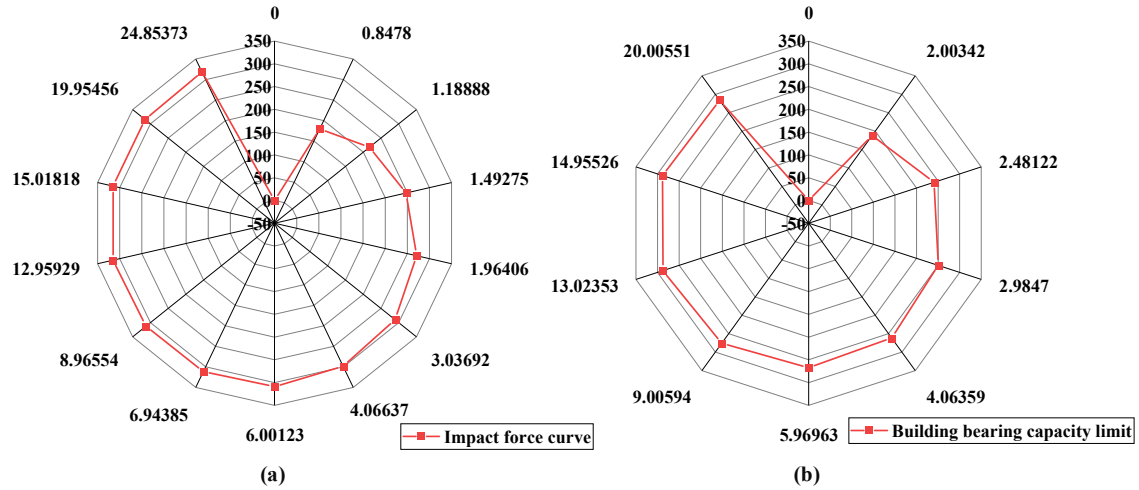

Figure 8. simulation diagram of impact force curve and ultimate bearing capacity of steel beam joints (a: impact force curve; b: bearing capacity limit of steel beam joints)

Conclusions can be drawn from the impact force curves and the ultimate bearing capacity simulation diagram of steel beam joints in Figures 8a and 8b. In the initial stage of impact force application, that is, the pulse stage, the force on the node shows an increasing linear trend. When the impact force is in the first and second stage of the platform stage and sub pulse stage, the stress of steel beam joints tends to be gentle and stable. It reveals that the model has a high impact bearing capacity and good seismic capacity of the building structure.

On this basis, the analytical tests of skeleton displacement of joints under impact are further carried out. When the cyclic superposition of the impact force increases the peak value of the pulse stage, the relationship between the magnitude of the node displacement and the bearing degree of the node to the impact force is simulated. Figure 9 shows the simulation results of the relationship between impact force and structural displacement.

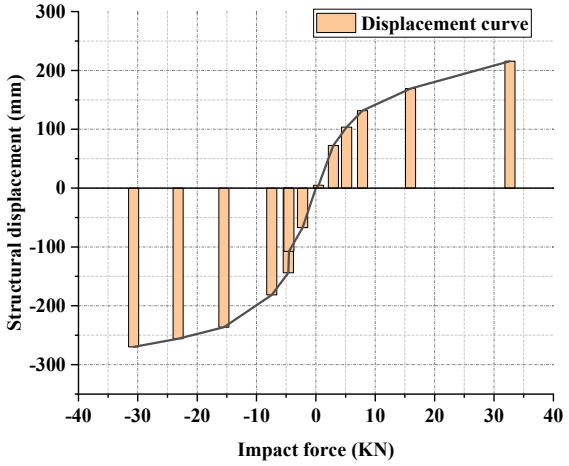

Figure 9. simulation results of the relationship between impact force and structural displacement

The displacement curve can express the relationship between the applied impact force and the joint damage displacement. When the cyclic superposition of the impact force increases the peak value in the pulse stage, the magnitude of the node displacement indicates the bearing degree of the node specimen to the impact force. Figure 9 suggests that the maximum displacement between node

members shall not exceed 300mm when the model is impacted again. It can be concluded that the model has a high impact bearing capacity, so it has a strong seismic capacity.

3.2 Seismic performance analysis of integral building structure

Under the action of impact force, the performance degradation of the building structure is manifested in the degradation of bending rigidity and bending strength. Figure 10 shows the degradation of bending rigidity and bending strength.

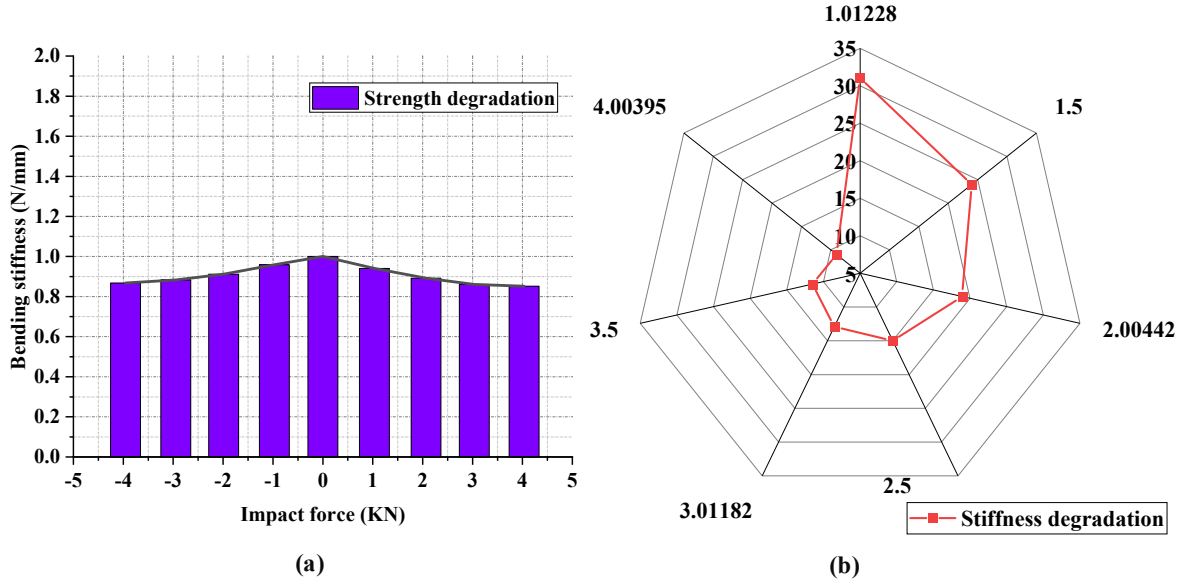

Figure 10. degradation curve of bending stiffness and bending strength (a: strength degradation; b: stiffness degradation)

Under the action of impact force, the performance degradation of the building structure is manifested in the degradation of bending rigidity and bending strength. Figure 10a presents strength degradation data, and Figure 10b displays stiffness degradation data. The decrease of stiffness indicates that the deformation resistance of the building structure against the impact force is weakened, and the decrease of strength indicates that the bearing capacity of the building structure against the impact force is weakened. The overall analysis shows that the stiffness and strength decrease significantly after the impact force pulse stage. However, when the impact force enters the platform's stages 1, 2 and sub pulse, bending stiffness and bending strength decrease is more obvious. However, the decline is small and slow. The strength change is within 0.2 and the stiffness change is within 2, which meet the requirements of seismic deformation. Therefore, the model has good performance and anti-degradation ability, so it has a strong seismic ability. To sum up, the model test shows that the carefully designed building structure has a reasonable structural layout, strong bearing degree of vibration impact force, the strong anti-degradation performance of stiffness and strength performance and large torsional stiffness. The overall seismic performance is good and can meet the seismic fortification requirements.

4. Conclusion

The scale of recent earthquake disasters in the world is large. In addition to objective factors, it is mainly because the buildings where human beings are located have not been well designed for earthquake resistance, which further increases the degree of disasters. The causes of damage and collapse of buildings in the earthquake are deeply analyzed. It is found that building earthquake-resistant buildings that can withstand strong earthquakes is the most direct and effective way to reduce earthquake disasters. First, the theoretical overview of seismic engineering and related form and

requirements of the building structure are studied in detail. Next, the building node structure is deeply analyzed according to the knowledge of fluid mechanics and the basic idea of the finite element method of integral structure. The seismic performance of building structures and the principles and requirements of seismic engineering are analyzed and summarized. It is found that the concrete analysis and description of seismic performance in the research method of fluid mechanics is a steel structure's bending resistance, deformation and displacement degree, and the bearing degree of external impact force under an impact force. Further, the model design of the integral structure is carried out through the finite element idea of fluid mechanics. Then, the model simulation experiment is conducted to obtain the curve of the impact force on the building structure, the ultimate bearing capacity of the steel beam joint and the skeleton displacement under the impact. Meanwhile, the degradation of stiffness and strength of node structure during an earthquake is analyzed. Finally, the simulation results show that the maximum displacement between joint members does not exceed 300mm under the action of impact force. Moreover, the anti degradation ability of flexural stiffness and strength performance is also good, so the model has high impact bearing capacity and strong seismic capacity, which can meet the seismic fortification requirements. Therefore, this exploration will be of great significance to the development of building seismic engineering under the guidance of fluid mechanics. The research deficiency is that the modeling speed of complex building structures is slow when the general finite software is used for dynamic elastic-plastic time history analysis of building structures. Moreover, there is no further study on its damage mode. Therefore, the next main work is to further analyze its hysteretic energy consumption and damage mode. Studying the distribution of hysteretic energy consumption along the floor will be more valuable.

Acknowledgments

Funding Statement: This study was sponsored by the "Key Scientific and Technological Projects of Henan Higher Eduction" (Project name: Research and application of key welding technology for long-span steel box girder; grant number: 23B560015; https://hnapp.rcloud.edu.cn/articleAction/to_view.do?id=ff80808183356d5e018378f99fe6077e&sysMenu.menuId=C732244EA3550451E040007F010003CE; A. W).

Funding Statement: This study was sponsored by the "Key Scientific and Technological Projects of Henan Province 2022" (Project name: Research and application of key welding technology of fabricated u-ribbed stiffened steel bridge deck; grant number: 222102320267; http://kjt.henan.gov.cn/2022/01-27/2389939.html; A. W).

References

[1] Ali, M., & Hasan, B. O. (2020). Galvanic corrosion of carbon steel under concentration cell formation in mgcl2 solution as an inorganic pollutant and the effect of flow velocity. Corrosion Reviews, 38(3), 287-298.

[2] Varnavides, G., Jermyn, A. S., Anikeeva, P., Felser, C., & Narang, P. (2020). Generalized electron hydrodynamics, vorticity coupling, and hall viscosity in crystals. arXiv e-prints, 11(1), 1-6.

[3] Buckmaster, T., & Vicol, V. (2020). Convex integration constructions in hydrodynamics. Bulletin of the American Mathematical Society, 58(1), 1.

[4] Jia, Y., Shang, L., Nan, J., Hu, G., Fang, Z. (2022). CFD Analysis of Fluid-Dynamic and Heat Transfer Effects Generated by a Fixed Electricity Transmission Line Interacting with an External Wind. FDMP-Fluid Dynamics & Materials Processing, 18(2), 329–344.

[5] Kitayama, S., & Constantinou, M. C. (2018). Seismic performance of buildings with viscous damping systems designed by the procedures of ASCE/SEI 7-16. Journal of Structural Engineering, 144(6), 04018050.

[6] Escobar, J., Nieland, J., Houselt, A. V., Zhang, X., & Lohse, D. (2020). Marangoni puffs: dramatically enhanced dissolution of droplets with an entrapped bubble. Soft Matter, 16(18), 1260-1269.

[7] Vacondio, R., Altomare, C., Leffe, M. D., Hu, X., & Souto-Iglesias, A. (2020). Grand challenges for smoothed particle hydrodynamics numerical schemes. Computational Particle Mechanics, 67(21), 1-14.

[8] Rosswog, S. (2020). The lagrangian hydrodynamics code magma2. Monthly Notices of the Royal Astronomical Society, 498(3), 4230-4255.

[9] Han, M., Fruchart, M., Scheibner, C., Vaikuntanathan, S., Irvine, W., & Pablo, J. D., et al. (2020). Statistical mechanics of a chiral active fluid, 17(11), 1260-1269.

[10] Malvania, N., Zhang, Y., Le, Y., Dubail, J., & Weiss, D. S. (2021). Generalized hydrodynamics in strongly interacting 1d bose gases. Science, 373(6559), 1129-1133.

[11] Wang, Y., Ma, C. (2022). CFD-Based Numerical Analysis of the Thermal Characteristics of an Electric Vehicle Power Battery. FDMP-Fluid Dynamics & Materials Processing, 18(1), 159–171.

[12] Haberstroh, C. J., Arias, M. E., Yin, Z., & Wang, M. C. (2020). Effects of hydrodynamics on the cross: ectional distribution and transport of plastic in an urban coastal river. Water Environment Research, 93(2), 186-200.

[13] Shu, C., Wang, H., Li, X., Fan, J., & Ye, X. (2020). A thermo–hydro–mechanical model: capturing the effects of initial permeability and gas pressure on outburst-prone indicators. Natural Resources Research, 29(3), 1897-1914.

[14] Jin, L., Khajehtourian, R., Mueller, J., Rafsanjani, A., & Kochmann, D. M. (2020). Guided transition waves in multistable mechanical metamaterials. Proceedings of the National Academy of Sciences, 117(5), 201913228.

[15] Li, P., Wang, L., Zhao, F., Feng, S., Zhang, Q., Zhao, H., et al. (2021). Design of flexible multi-level topography for enhancing mechanical property. Nano Select, 2(3), 541-548.

[16] Lu, C., Lin, T., Cao, J., Yin, S., Gao, P., et al. (2021). Microstructure evolution and fire-resistant properties of 690 mpa anti-seismic fire-resistant steel plate. Materials Research Express, 8(6), 066523.

[17] Lorenzi, T., Murray, P. J., & Ptashnyk, M. (2019). From individual-based mechanical models of multicellular systems to free-boundary problems. Interfaces and Free Boundaries, 22(2), 205-244.

[18] Zhu, L., Wang, A., Jin, F. (2021). Using Image Processing Technology and General Fluid Mechanics Principles to Model Smoke Diffusion in Forest Fires. FDMP-Fluid Dynamics & Materials Processing, 17(6), 1213–1222.

[19] Tian, J., Song, M., Zhang, M., & Pan, J. (2021). Exploration into the anti-seismic technologies in the museum. IOP Conference Series: Earth and Environmental Science, 719(4), 042005.

[20] Jauhari, M. F., Fardheny, A. F., & Prasetia, E. I. (2020). Nonlinear Time History Analysis of Anti Seismic Device on Highway Bridge. Int. J. Adv. Sci. Res. Eng, 6(6), 33-39.

[21] Oh, S. K. (2021). Anti-seismic performance evaluation of waterproofing materials for underground pile wall structures. Materials, 14(19), 5719.

[22] Hua, J., Wang, X. & He, S. . (2012). Numerical simulation of impact tests on reinforced concrete beams. Materials & Design, 39(8), 111-120.