Innovative Design of Household Earthquake Rescue Products Based on Design Thinking and FAST Method

Yun Zhao
Kongjiang High School, Shanghai, China

Abstract: Earthquake disasters pose a significant threat to human life and property worldwide. To improve families' ability to survive earthquakes, innovative design of household earthquake rescue products using design thinking and functional analysis system technology (FAST) has become an effective method. The FAST method helps designers clarify the core tasks of products and innovatively optimize their structure and user experience. This design combines common emergency situations in earthquakes, such as taking refuge, seeking help, and obtaining emergency supplies. By combining design thinking and the FAST method, the design process becomes more systematic and innovative, ultimately achieving the best balance between product functionality and user experience, and providing strong protection for family survival and self-rescue in earthquakes.

Keywords: Product Demand; Artificial Intelligence; Structural Calculation; Earthquake Rescue

1. Background

Earthquake activities in my country are widespread, with high frequency and intensity, and shallow epicenters. Many provinces have experienced strong earthquakes. Since 1900, mainland China has had 1,992 earthquakes of magnitude 5 or above, and 70 of magnitude 7 or above. China has accounted for about 35% of world's strong earthquakes of magnitude 7 or above. However, despite this, compared to other countries, our earthquake resistance methods and products need improvement.[1]

Earthquake emergency rescue products are divided into four categories: facilities for buildings, supplies for self-rescue, equipment for rescue personnel, and rescue materials. These products help reduce earthquake disasters and are developed by professional companies and approved by the Japan Disaster Prevention Association. This article focuses on the system design strategy for the first 72 hours after an earthquake, known as the "golden period" for rescue efforts. The time before, during, and after an earthquake is divided into three periods: pre-earthquake prevention, epicenter escape, and post-earthquake rescue. These periods correspond to three categories of rescue products developed for human survival needs: pre-disaster protection, individual survival in disasters, and post-disaster rescue. However, there is a lack of demand research and designs for individual survival products, and the production of emergency shelter products in China started late. During an earthquake, people in high-rise and large non-high-rise buildings should quickly find a safe area indoors, such as the bathroom or kitchen, and these areas should be considered for survival product design. After the earthquake, safe triangles in the building can be used as survival space for evacuees and should be considered in survival product design.

2. Research on Earthquake Rescue Issues based on Design Thinking and FAST Method

2.1 Theoretical Basis: Design Thinking and FAST Method

The term "Design Thinking" has attracted attention in the business field since the 1980s and 1990s in the United States, when professors of design at Harvard University and Stanford University first defined and proposed this concept. In 1992, Richard G. Buchanan, a famous designer and professor at Carnegie Mellon University, published his famous article "Wicked Problems in Design Thinking", which discussed the many fundamentally difficult to define difficulties people encounter in production and life practices. These are the so-called "Wicked problems", and design thinking can play a special role in this type of problem seen in figure 1.[2]

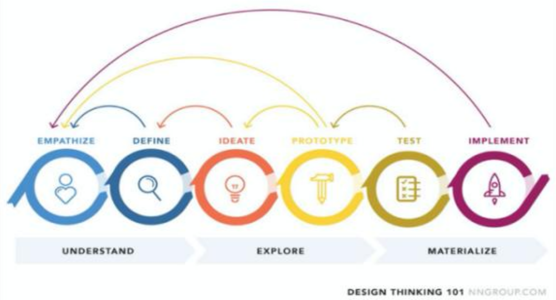


Figure 1. Design Thinking.

Empathize, or understanding user needs, is a people-centered stage. Through observation and other methods, analyze the core demands of users. Next, define the problem with people as the center, distinguishing what's important to users. Ideate, or enhance creativity, using methods like brainstorming and sketching. Prototype, designing a product or solution, then select and design a detailed solution. Test the design, verify the solution, and improve it. The core value of the testing phase is the spirit of iteration.[3]

FAST method

FAST, or Function Analysis System Technique, is a method used to define, analyze and understand the functions of a product. It focuses on determining the primary and secondary relationships between product functions and identifying the important or "basic" functions. Functions are created and sorted in a logical order, with the interdependence between functions tested by sorting primary and secondary functions. The method involves analyzing all product functions from the user's perspective through questions and answers. Functions are then defined using simple words, like verbs plus nouns or gerunds, to help designers screen the product functions. From the user needs perspective, the basic functions of a product are the most important and serve as the basis for product existence and selection. Each product has its own basic functions, which can help reduce complexity in product function design and improve the effectiveness and efficiency of product functions, ultimately meeting user needs.[4]

2.2 Analysis of Earthquake-Affected Population

Human behavior is the external manifestation of psychological activities. In general, in the study of individual behavior characteristics after a disaster, the behaviors of disaster victims are divided into eight categories: general evacuation behavior, leadership behavior, altruistic behavior, escape behavior, selfish behavior, deviant behavior, wooden chicken behavior and over-defense behavior. The evacuation behavior of disaster victims varies greatly due to individual and environmental differences, but these behaviors are basically low-rational or even irrational social behaviors under psychological states such as tension, extreme fear, and cognitive dissonance.

The outbreak of an earthquake can instantly switch people's psychology to a stress state. It is a tense reaction caused by the incompatibility between the objective changes in the environment and the individual's subjective coping ability after people are subjected to the external stimulus of a sudden disaster. In earthquake disasters, people's psychology can be divided into three levels according to Donald Norman's emotional design theory: instinctive level, behavioral level and reflective level. The instinctive level can most directly reflect the psychological characteristics of people when facing sudden disasters. At the moment of an earthquake, the drastic changes in the surrounding environment will cause people to temporarily lose their rationality and ability to control their actions. They generally show negative emotions such as anxiety, tension, panic and confusion. At this stage, people's behavior is mainly dominated by subconscious and irrational factors. The psychological activities at the behavioral level are mainly reflected in the escape process and the process of waiting for rescue. When actively escaping, people's senses and cognitive systems will quickly establish a human-machine connection with the product, but in an emergency such as an earthquake. People's recognition ability and various mobility capabilities will drop significantly. At the same time, they will be accompanied by strong anxiety and frustration. While waiting for rescue, long waiting and dark environment will cause negative emotions such as helplessness.

2.3 Problem-Oriented Analysis of Home Earthquake Scenarios

"Problem-oriented" design thinking mode

involves analyzing and solving essential problems behind a phenomenon. Design behavior must be based on accurate problem understanding. The design object is analyzed at three levels: basic, core and extended problems, to clarify problem type and nature, decompose problem elements, find solutions and complete the design task. Accurate problem definition determines the design value, and re-decomposing the defined problem affects solution feasibility. Basic problems are caused by design object's basic conditions like working environment and facilities. Core problems arise from design object's core function defects. Extended problems from lack of auxiliary function. The auxiliary function concerns enhancing object's connotation and forming a friendly user experience as in figure 2. [5]

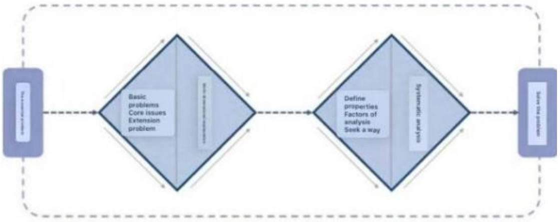


Figure 2. Problem-Oriented Design Thinking.

2.4 Earthquake Rescue Product Requirements-Function Analysis based on FAST Model

People's psychological reactions are reflected in three levels in figure 3: instinct, behavior, and reflection. The instinct level is the level of people's direct perception, which is reflected in the choice of physical characteristics of products. The behavioral level is the level of people's senses, which is reflected in the product's function, understandability, usability, and physical feeling. Function means realizing needs. Understandability means that users do not need to repeat or further explain. Usability means the versatility and difficulty of operation give users a sense of control. The reflective level is a deeper level of experience, reflected in satisfaction and memories.[6]

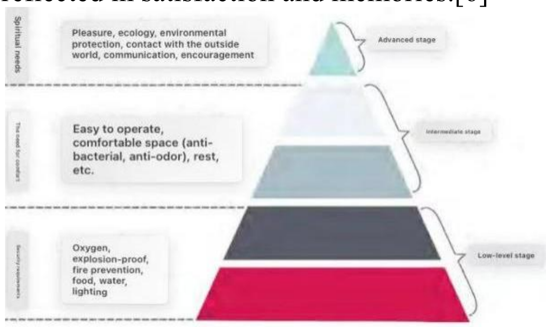


Figure 3. People's Psychological Reaction Level.

The FAST method creates a function tree to analyze and model product functions. Start with the main function in the top left, then add sub-functions on the right to complete it. The path from the main function to the end is the critical path; any sub-functions after this aren't part of the product function. After analyzing the critical path, examine the sub-functions and create new ones to manage any side effects. These new functions are listed below the critical path sub-functions. Some sub-functions not on the critical path are also listed above the function tree, with certain functions categorized based on their purpose. By creating the FAST function tree, the product's overall functions structure can be visualized, and sub-functions can be developed to optimize function problems and realize new available functions. The function tree also helps to maintain a balance between function and cost, keeping both within a moderate elastic range.[7]

Table 1. Earthquake Emergency Products.

	Functional requirements	Comfort Factor	User Experience	Effect evaluation
Earthquake Relief	Active rescue	Availability	Design Details	Safe, efficient and comfortable
	fold	Spatial Layout	Easy to discover	
	Anti-collision	size	Color Matching	
	Strong and stable structure			
	Easy to operate			
Daily use	Plenty of sleeping space	Ergonomics: Bed length 1.8m Bed width 1.2m Bed height 0.9m	Material texture	
	No safety hazards in normal use	Storage space	Visual form	

Earthquake emergency products have unique usage scenarios, different from general products. Their development cannot be approached like ordinary consumer products. The external and psychological environment during an earthquake influences the use of these products, making their usage "irrational" and "unconventional". This highlights that the development of personal earthquake emergency products requires a focus on the "emergency" psychological use model, rather than just a simple accumulation of functions. The product design should be simple, clear, and powerful to reduce cognitive and operational errors and guide users to make correct usage behaviors at the subconscious level.[8]

3. Research Results

3.1 Solution Design

The FAST function tree of earthquake rescue products was used to regroup products by function integration, user experience, structure and function expansion. This helped in obtaining more principal explanations and generating technical solutions, which served as a reference for product design. The analysis of environmental resources and functions revealed a certain matching relationship between general home facilities and disaster prevention products. Through this analysis, corresponding facilities can be functionally matched and integrated, although technical and physical contradictions may arise. The research object for system design is the highly utilized bed in the home, which can meet the function of combining flat and seismic.

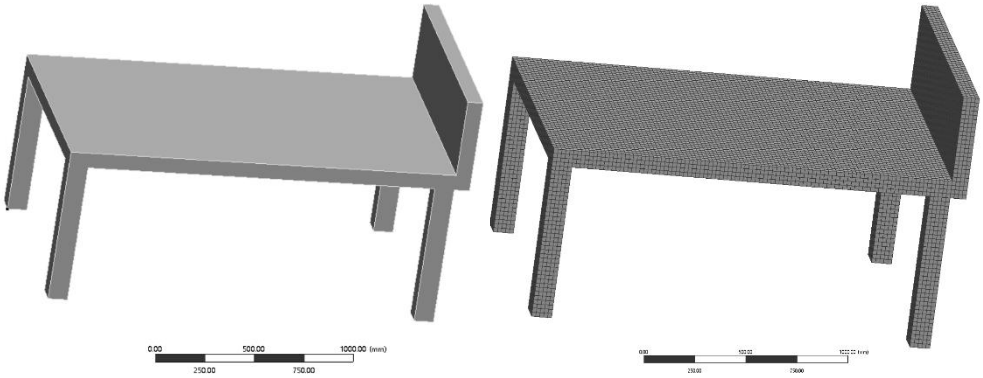
The FAST model analyzes system contradictions. Emergency shelter products must serve both normal and disaster times, possessing flexibility, disaster prevention, closure, and adaptability to the environment. The design of the bed must accommodate variability in structure and material to meet these requirements, but changes can increase complexity. The technical contradiction is "adaptability" vs "complexity". The physical contradiction, obtained through FAST model analysis, is that products must be adaptable and simple to use. Time separation method is used to solve physical contradictions, conforming to the concept of combining flat and seismic solutions. After solving technical and physical contradictions, a common invention principle, the dynamic principle, is obtained which includes changes in materials, folding, state transformation, and flexible deformation.[9]

Figure 4. Bed Board Test When an Earthquake Occurs.

Based on the existing 1.2-meter single bed in figure 4, the bed board is divided into two parts 1 and 2 and connected by hinges. When an earthquake occurs, the bed boards 1 and 2 are rotated to form a triangular refuge space together with the head of the bed, and are connected and fixed by the bed board 3 to ensure the stability of the space.

3.2 Material selection

The material design for modern housing floors primarily uses steel structure and wood board for their high hardness, meeting emotional experience needs and improving security. Color selection in earthquake emergency products has symbolic meanings guiding usage and emotions. Warm colors bring excitement and warmth, while cold colors represent calmness and rationality. White is used in post-disaster medical relief products due to its hygienic connotations. ANSYS simulations of total deformation and total stress in a bed under earthquake conditions help evaluate and improve its seismic performance. This analysis reveals the bed's behavior under actual earthquake conditions, optimizing structural design and ensuring safety and stability. Total deformation refers to displacement under load, reflecting the stiffness of the structure, and is crucial for stability and safety evaluations. Total stress analysis predicts stress distribution and concentration areas, identifying possible failure modes and structural strengths. Force assumption: A 10kg stone falling 2 meters generates an impact of 0.626MPa over 1s.[10]



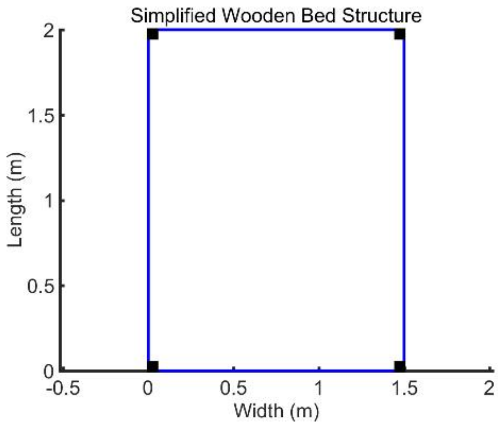
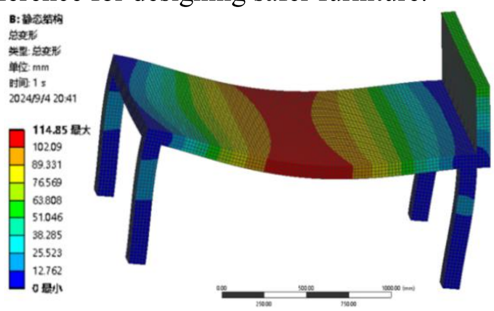
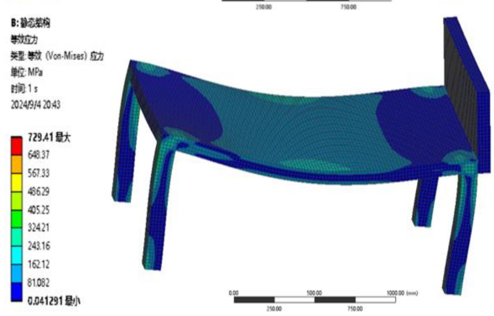
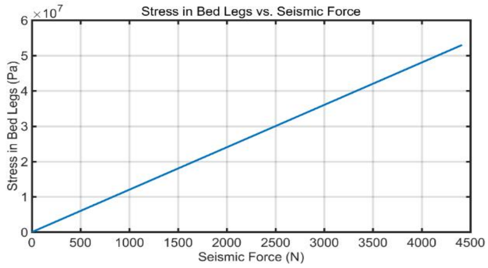


Figure 5. Bed Structure Simplified

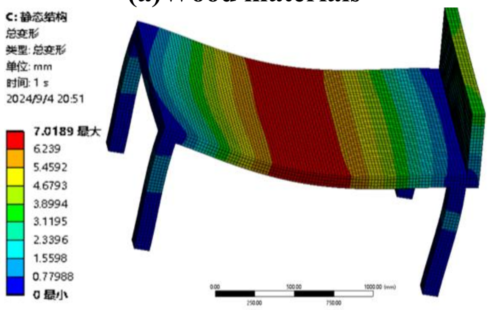
The bed is simplified into a rectangular frame consisting of four vertical supports (bed legs) and four horizontal supports (bed frame) in figure 5. The mechanical properties of different materials, such as elastic modulus, density, yield strength, etc., determine the stress distribution and deformation degree of the bed when subjected to external forces (such as earthquake forces). In an earthquake, horizontal forces (usually inertial forces caused by earthquakes) will act on the structure of the bed, especially on the joints and support legs of the frame. This force can be simulated as the mass of the bed multiplied by a part of the earthquake acceleration. In some cases, earthquakes may also generate vertical forces. These forces affect the bearing capacity of the bed legs and the stability of the entire bed frame. Using these simple mechanical models and assumptions, we can roughly estimate the structural strength of wooden beds in earthquakes, and thus determine whether the bed can effectively protect the people above it in earthquakes. This analysis can provide a preliminary safety index for wooden beds under earthquakes for people in earthquake zones, and provide a reference for designing safer furniture.

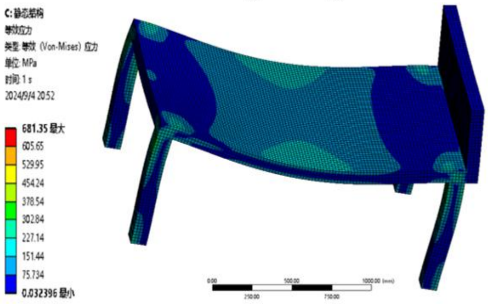


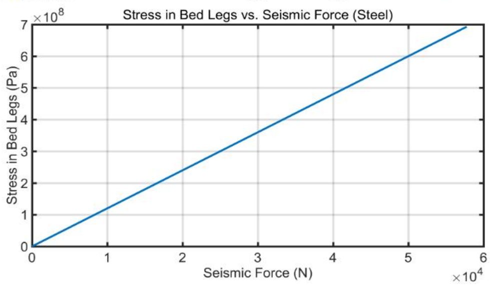




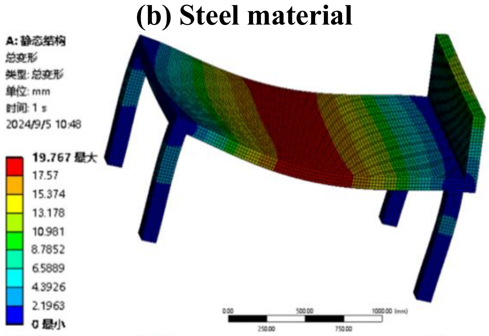
(a)Wood materials

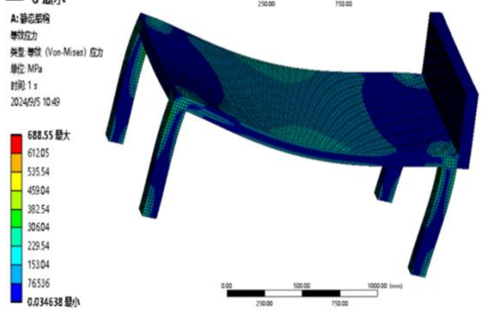


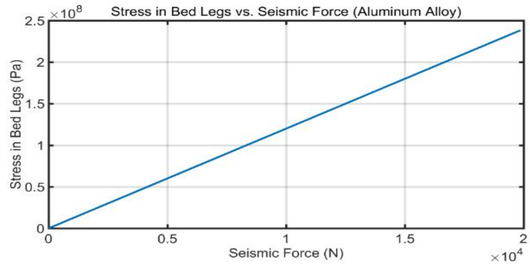




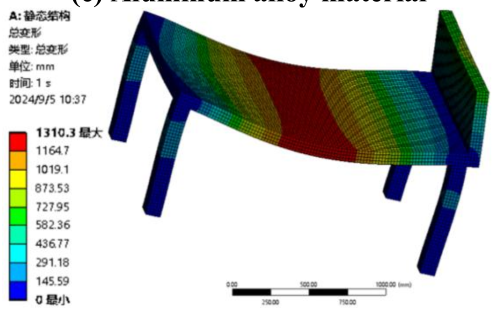
(b) Steel material

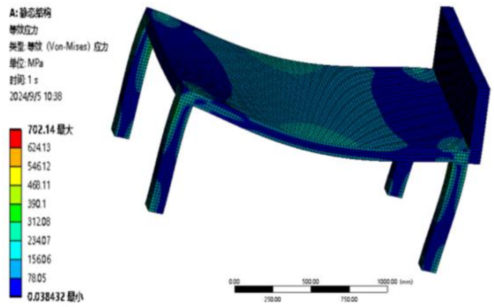


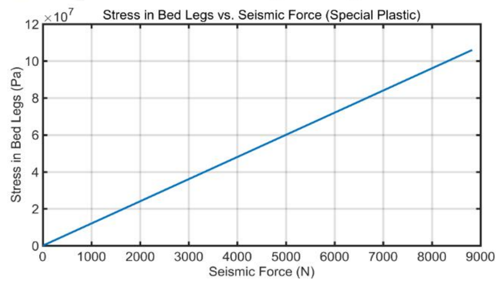




(c) Aluminum alloy material







(d) Special plastic materials

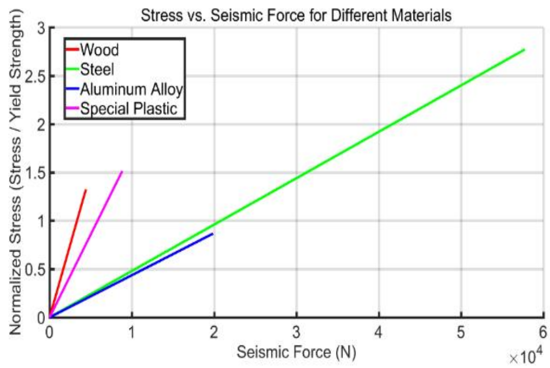


Figure 6. Comparison of Different Materials

The following table 2 comparing the four materials (wood, steel, aluminum alloy, and special plastic).

3.3 Optimize the Seismic Resistance of Bed

Legs

The addition of angled legs to steel beds can improve their earthquake resistance by changing the angle of the bed legs. This force decomposition reduces the impact of the horizontal force on the bed legs, enhancing the stability of the structure. Bed legs with a larger inclination angle can better disperse the earthquake force, reducing the risk of the bed frame overturning. By changing the angle of the steel bed legs, the earthquake resistance of the bed can be improved, reducing stress concentration and material fatigue, and increasing safety and service life. This design idea, especially in earthquake-prone areas, can significantly improve the overall performance of the bed in earthquakes. Therefore, the change in angle affects the structural stiffness and stability of the bed, thereby improving its earthquake resistance as shown in **figure 7 and figure 8**.

Table 2. Material Comparison.

Material	advantage	shortcoming	Applicable scenarios
wood	Lightweight Low cost Renewable Resources Easy to process	Low elastic modulus and yield strength applications that are subject to high stress	Furniture or decorative purposes that do not require high strength
Steel	High elastic modulus and yield strength Strong carrying capacity Suitable for structural applications requiring high strength	High density and heavy weight Prone to corrosion, requires rust prevention treatment	Highly loaded structures such as buildings and industrial equipment
Aluminum Alloy	Lightweight High strength Strong corrosion resistance Easy to process	Higher cost Lower elastic modulus requires thicker structures to maintain rigidity	Applications that require lightweight and corrosion resistance, such as aerospace, transportation
Special plastics	Lightweight Strong corrosion resistance Easy to process May have some flexibility	Low elastic modulus and yield strength Limited carrying capacity	Lightly loaded structures or applications requiring corrosion resistance and lightweighting, such as consumer products and industrial applications

3.4 Intelligent Identification of Earthquake Beds

The model assesses if a person is still alive during an earthquake by considering the magnitude threshold, bearing capacity of the bed, and safety condition. If the seismic forces exceed a preset safety threshold and the stress of the bed structure exceeds the yield strength of the material, it may cause harm to personnel. The safety threshold determines the limit of seismic forces under which the bed structure can ensure people's safety. The model's judgment of people's safety depends on the comparison of stress and yield strength and whether the seismic forces exceed the set safety range.

3.5 Human - Machine Engineering and Intelligent Identification

The design of earthquake emergency products aims to improve the user experience and guide behavior through appropriate modeling and color matching. The products primarily serve an indicative and safety function, with the former ensuring clear instructions and the latter providing psychological security through robust designs. It is important that these products do not convey negative semantic feelings.

3.6 Design Evaluation

The product is verified through the design walkthrough method, and senior product designers and human-machine structural engineers are organized to evaluate and analyze the design plan, score it on a 5-point scale, and propose improvement directions. From the perspective of child safety, we ensure the design points such as humanized design, reasonable functions, ergonomics, system design, quality and aesthetics to maximize the rescue efficiency.

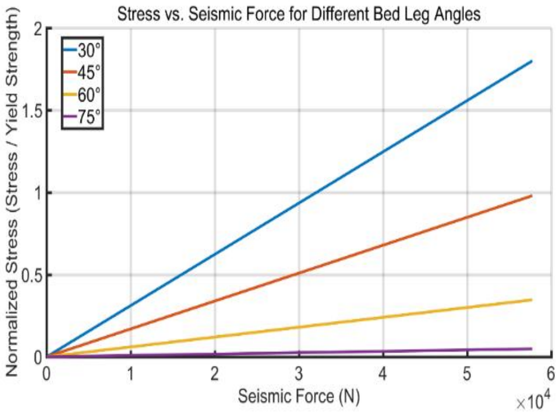


Figure 7. Comparison of Bed Legs with Different Angles

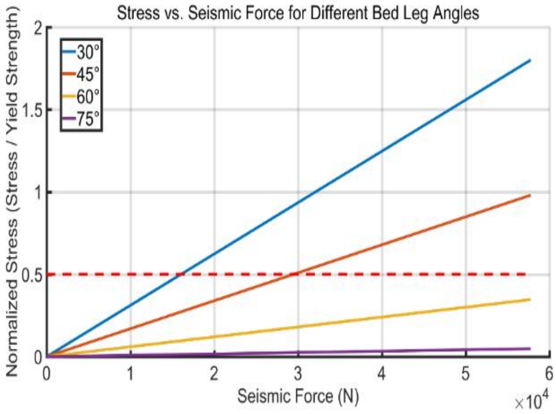


Figure 8. Relationship between Bed Leg Stress and Seismic Force at Different Angles for Personnel Safety.

4. Conclusion

(1) Steel has high density, heavy weight, high elastic modulus and yield strength, and strong bearing capacity, making it suitable for structural applications requiring high strength.
(2) Maximum stress of the bed legs at an angle of 30° : 4.50e+08 Pa, yield strength: 2.50e+08 Pa, ratio of maximum stress to yield strength: 1.80, personnel safety status: the seismic force is within the safe range and personnel are safe.
(3) Since the structure of a folding bed is different from that of a flat bed, its seismic performance may also be different. Therefore, in future research, ANSYS Workbench simulation analysis can be performed on the folding bed to evaluate its total deformation and total stress during an earthquake, thereby improving the seismic performance of the folding bed.

References

[1]Zhao Feng, Wang Kenan, Zhu Fangfang. Design of campus earthquake emergency shelter products based on TRIZ[J]. Packaging Engineering, 2018, 39(14): 8-12. DOI:10.19554/j.cnki.1001-3563.2018.14.002.
[2]Zhao Fei, Xu Na. Modular design of flood accident rescue products based on FAST method[J]. Packaging Engineering, 2020, 41(16): 141-146. DOI:10.19554/j.cnki.1001-3563.2020.16.021.
[3]Lou Shuting, Liu Wenjing, Pan Yunqing, et al. Design of portable earthquake rescue assistance products[J]. Science and Technology Vision, 2014(04): 188+151. DOI:10.19694/j.cnki.issn2095-2457.2014.04.143.
[4]Li Xiaofeng, Cheng Si, Wang Yunan, et al. Emotional design of earthquake emergency rescue products[J]. Packaging Engineering, 2011, 32(02): 44-47. DOI:10.19554/j.cnki.1001-3563.2011.02.014.
[5]Cao Lirui. Demand analysis of personal survival products in earthquake disasters[J]. Industry and Technology Forum, 2014, 13(11): 81-84.
[6]Wang Yunan, Xu Xiaole, Wang Xiaochun. Research on product design methods based on typical scenarios of earthquake prevention and disaster relief[J]. Packaging Engineering, 2010, 31(14): 15-17+28. DOI:10.19554/j.cnki.1001-3563.2010.14.006.
[7]Wang Kenan, Zhao Feng. Research on earthquake campus emergency shelter product design based on TRIZ[J]. Industrial Design, 2017(02): 85-87.
[8]Chen Li, Jia Sixuan. A brief analysis on the standardization of household earthquake emergency preparedness products[J]. China Disaster Reduction, 2022(23): 48-49.
[9]Zhang Mingchi, Zhang Linghao. Earthquake emergency product development based on system design thinking[J]. Packaging Engineering, 2010, 31(14): 18-21. DOI:10.19554/j.cnki.1001-3563.2010.14.007.
[10]Han Jun, Chen Derun, Deng Chengfeng. Problem-oriented design of fire rescue

products for old residential areas[J]. Packaging Engineering, 2022, 43(06): 110-118. DOI:10.19554/j.cnki.1001-3563.2022.06.015.