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Expert Opinion Article

Design And Simulation Based Improvement Of A Portable Curb Climbing Aid For Wheelchair

Dr. Raj Kumar Easwarapillai[1*], Dr. Bindu. S. S[2], Sree Raj M. P[3], Manoj.A[4], Saurav. R. Vimal[5], Aswin.S[6]

[1*]Professor, Rajadhani Institute of Engineering and Technology, Department of Mechanical Engineering, India
[2] Associate Professor, Rajadhani Institute of Engineering and Technology, Department of Mechanical Engineering, India
[3] Assistant Professor, Rajadhani Institute of Engineering and Technology, Department of Mechanical Engineering, India
[4]Associate Professor, Rajadhani Institute of Engineering and Technology, Department of Mechanical Engineering, India
[5]Assistant Professor, Rajadhani Institute of Engineering and Technology, Department of Mechanical Engineering, India
[6]Lab Instructor, Rajadhani Institute of Engineering and Technology, Department of Mechanical Engineering, India

***Corresponding Author:** Dr. Raj Kumar Easwarapillai
Email: rajkumarpillai2020@gmail.com

Abstract:
The proposed aid is designed to be arranged and operated by the wheelchair occupant without external assistance. Although several existing designs attempt to address curb climbing challenges, most rely on complex mechanisms, powered systems, or sophisticated controls, making them expensive, heavy, and impractical for household or everyday use. At present, there are no widely available solutions within an economical range that effectively meet the needs of a broad user population. The objective of this work is to develop a simple, low-cost, and user-friendly design that is feasible for users across different economic backgrounds. The proposed system consists of detachable attachments that can be manually deployed by the occupant with minimal physical effort. The design emphasizes affordability, ease of operation, and compatibility with conventional wheelchairs. The study involves analyzing the forces acting on the ramp during wheelchair traversal and using these results to design an appropriate and structurally safe ramp. In addition, mechanical stops are incorporated to arrest the attachments at predefined positions, eliminating the need for complete removal during operation. A slight eccentricity is introduced in the attachment at the axle to improve reachability and ease of handling for the occupant. Overall, the proposed design aims to provide a practical, economical, and effective solution for independent curb climbing by wheelchair users. This paper focuses on the design of a wheelchair equipped with an assistive aid that enables users to climb roadside curbs independently.

Keywords: Wheel chair, Ramp, Mechanical stop, Independent curbs climbing.

1. Introduction:

Currently, more than 40 million people worldwide rely on wheelchairs for mobility, with the majority using them primarily within home and community environments. Despite continuous advancements in wheelchair technology, conventional wheelchairs both manual and powered still face significant limitations when encountering common environmental barriers such as roadside curbs. Crossing curbs remains a challenging and often unsafe task, restricting independent mobility and reducing accessibility in everyday urban settings. To address this issue, various curb- and stair climbing wheelchair designs have been proposed in the past. Many of these solutions employ complex mechanical systems, high powered actuators, or sophisticated control mechanisms to enable curb negotiation. While technically effective, such designs often result in increased weight, high manufacturing costs, and complex maintenance requirements. Consequently, these systems are unaffordable and impractical for a large segment of wheelchair users, particularly in low and middle-income regions. Several researchers and designers have attempted to develop simpler curb climbing aids; however, many of these solutions lack time efficiency, ease of use, or universal compatibility with different wheelchair types. In particular, manual deployment mechanisms can be cumbersome and physically demanding for users and caregivers, limiting real world applicability. These limitations highlight the need for a low-cost, lightweight, and user friendly solution that can be easily integrated with existing wheelchairs. This paper addresses these challenges by focusing on the design of a portable ramp and an attachment mechanism for wheelchairs that facilitates safe and efficient curb crossing. The proposed design aims to strike a balance between simplicity, affordability, and functionality, avoiding complex machinery while maintaining sufficient structural strength and usability. By emphasizing ease of deployment and adaptability, the developed ramp and attachment system seeks to improve independent mobility for wheelchair users and provide a practical alternative to existing curb-climbing solutions.

2. Literature Review

Wheelchair mobility and postural support have been widely investigated due to their direct influence on independence, safety, and quality of life for individuals with mobility impairments. Numerous studies report that many children and adults are unable to maintain an upright sitting posture without additional support because of neuromuscular disorders, spinal deformities, aging-related conditions, or reduced trunk control. Inadequate postural support often results in discomfort, fatigue, pressure ulcers, and secondary musculoskeletal complications, highlighting the need for well-designed wheelchairs and supportive assistive devices [5], [6]. Early research and practice in wheelchair provision primarily relied on standardized designs, which frequently failed to accommodate individual user needs. As a result, later studies emphasized user centered and context-sensitive approaches to wheelchair design and service delivery. The World Health Organization (WHO) has strongly advocated that wheelchair provision should consider posture, stability, safety, and environmental barriers such as curbs and uneven terrain, particularly in low- and middle-income settings [5], [6]. These recommendations have encouraged researchers to focus on low-cost, lightweight, and adaptable assistive solutions that can be widely implemented. Advances in computer-aided design (CAD), computer-aided manufacturing (CAM), and rapid prototyping have significantly influenced the development of wheelchair accessories and assistive devices. Hieu et al. [1] demonstrated that medical rapid prototyping enables faster design iterations and improved customization of assistive products. Similarly, Alghazzawi [2] highlighted that modern CAD/CAM technologies allow practical and efficient implementation of customized medical and rehabilitation devices. Additive manufacturing and 3D printing, in particular, have gained attention for their ability to produce personalized assistive devices with reduced cost and manufacturing time. Studies have shown that 3D printing is especially effective in special education and rehabilitation contexts, where individual adaptation is critical [3], [4]. Modeling and simulation techniques have become essential tools in the evaluation and optimization of wheelchair-related assistive mechanisms. Finite element analysis (FEA) and simulation-based design approaches are widely used to analyze structural strength, load distribution, and stability under real-world conditions. These methods allow designers to predict system behavior, identify potential failure points, and improve safety prior to physical prototyping. Simulation-driven design is particularly valuable for assistive devices intended to overcome environmental obstacles, such as curb- and stair-climbing aids, where experimental testing can be costly and potentially hazardous. Curb negotiation remains one of the most common challenges faced by wheelchair users in everyday environments. Existing solutions reported in the literature include powered stair-climbing wheelchairs, detachable ramps, and lever-based or auxiliary curb-climbing aids. Although powered systems provide effective mobility over obstacles, they are often heavy, complex, and expensive, limiting their applicability in less-resourced settings [5]. In contrast, portable and lightweight curb-climbing aids have been proposed as more affordable alternatives. The portable ramp curb-climbing aid proposed by Roger N. White is frequently cited as an innovative low-cost solution; however, studies indicate that manual deployment and operational difficulty restrict its usability for a wide range of wheelchair users. Recent research emphasizes improving such low-cost designs through ergonomic optimization, improved mechanical design, and simulation-based refinement while maintaining affordability and simplicity. Human-centered design principles and usability studies stress that assistive devices must be intuitive, require minimal physical effort, and be compatible with different wheelchair configurations. Furthermore, adaptability and modularity are increasingly recognized as essential features to accommodate variations in user weight, wheelchair geometry, and environmental conditions.

3. Selection of wheel chair:

It is very important to select the right wheelchair .The correct size wheelchair is more comfortable, helps to support upright sitting and is easier for the wheelchair user to use.

Frame: whether it is a long or short wheelbase; the frame length; whether it is a cross-folding or rigid frame.

Features including the type of seat, backrest, footrests, armrests, castor wheels, rear wheels.

Wheelchair Size; This is usually described by the wheelchair seat width and sometimes also the depth. The seat height from the floor is also very important to know.

Adjustability Options; Adjustment is usually possible to two or more different positions. For example, most wheelchairs have which can be adjusted to different heights spaced evenly apart. The “range” of adjustments is from the smallest to the largest measurement.

Cushion; Determine which type of cushion (if any) is provided with the wheelchair or check can it be available separately.

3. Proposed Methodology

By creating a ramp attachment to the wheelchair which can be manually adjusted for any size curb. The material is supposed to be made of aluminium alloy completely as possible to reduce weight so that user can do the operation with less effort. The use of only mechanical attachments reduces the cost of wheelchair and can be afforded by common people To design wheelchair attachment to overcome curbs up to 15mm height .and easily usable by any user Low weight of wheelchair is required for easy manual manure. Two principally different wheelchairs were used in practice in which design of main wheel at rear was most commonly used. The other design with main wheel at front was not so frequent because of stability problems when moving forward on a down ward ramp. One commonly used was a 'Simens-Elema Komfort' with the main wheels at the rear, the dimensions of this wheelchair was directly taken for the design and ramps are designed accordingly .overall dimensions were taken into account in modelling wheelchair. Some manual wheelchairs have more features or adjustments than this. Some features or adjustments can be very helpful for wheelchair users who need additional postural support. These features include:

1. **Adjustable Footrests**

Most wheelchairs have footrests that can be adjusted up and down. Some have additional adjustments including moving forward or backwards and footrest angle can be increased or decreased. These adjustments give more flexibility to where the wheelchair user's feet can be placed.

2. **Elevating Leg Rests**

It can hold the foot up with knee extended. It is helpful for wheelchair users who cannot bend their knees to neutral for sitting.

3. **Backrest Recline**

It helps to accommodate. Hips that cannot bend to neutral sitting posture.Fixed posterior pelvic tilt. Fixed bent posture of lower trunk.

4. **Tilt in Space**

Tilted seat position can benefit. Fixed posterior pelvis tilt with hip and knee flexion contractures. Low sitting tolerance or discomfort during normal sitting position. To increase comfort and rest.

5. **Rigid Seat**

A good base to build additional postural support for the pelvis and hips. More stability than a slung seat. This can be beneficial if a wheelchair user has strong uncontrolled movements or is very heavy.

6. **Rigid Backrest**

More stability than slung/canvas backrest. This can be beneficial if a wheelchair user has strong uncontrolled movements. Better support for wheelchair users who are taller and heavier and/ or have very floppy trunks

4. Wheel chair specifications:

Postural support

All body contact surfaces provide seating and postural support. Together, these parts of the wheelchair help the user to maintain a comfortable and functional posture and to provide pressure relief. This is very important for users who have problems with skin sensation.

1. The distance between the seat and the centre of gravity of men is 305mm
2. Horizontal distance of centre of gravity and the main wheel axle is 222mm
3. Vertical distance of centre of gravity and the main wheel axle is 29mm
4. Weight of the wheel chair is 250N
5. Weight of the man acting on the wheel chair is 1000N
6. The coefficient of friction between the wheel chair tyre and the aluminium rim is 0.5
7. The distance between the back rest and the centre of gravity of men is 194mm

Virtual prototype:

Measuring a wheelchair user to select the correct wheelchair size and location of Postural Support Devices. On the measurements part of the intermediate wheelchair assessment form there are twelve body measurements listed. Six measurements are the same measurements as above in the Basic measurements. One additional backrest height body measurement is added to the intermediate wheelchair assessment form. Seat to top of shoulder measurement is used to measure a wheelchair user for a high backrest. There are six more measurements, which will help to decide the size and/or location of Postural Support Devices. Sometimes it may be necessary to take more measurements, depending on the Postural Support Devices prescribed. There is space on the intermediate wheelchair assessment form to record 'other' measurements

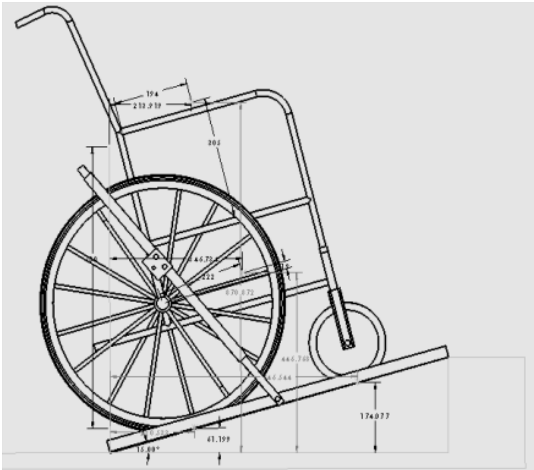

Fig. 1. 2D Design of wheel chair using Solidworks

The design shown above is a model converted into 2-D showing the positioning of C.G and dimensions regarding the positioning of ramp as shown in figure.1. The height of curb was taken as above mentioned. And the forces are calculated accordingly.

Fig. 2. 3D Design of wheel chair using Solidworks

5. Design Calculations

R1=reaction force between the front wheel and the rim

R2 =reaction force between the rear wheel and the rim

F1 = friction force between the rear wheel and the rim

F2 = friction force between the front wheel and the rim

5.1 Calculations are done using Moments at Different Point

Moment about P1 (Point of contact between rear wheel and ramp)

Moment about P2 (Point of contact between front wheel and ramp)

Moment about C.G (C.G of wheel chair)

Moment about P1 7×1000 + 442×R1 = 125×250 (442 = centre dist. between wheels, 125= dist. between rear wheel and C .G, 250 = weight of wheel chair, 1000 = wt of person, 7= dist. between rear wheel and C.G of person) R1=55

Moment about P2 R2 ×442=301×250+433×1000 (442 = centre dist. between wheels, 301 = dist. between front wheel and C.G of wheelchair, 433 = dist. between front wheel and C.G of person) R2 =1150

312 ×F2 +218×R1 +1000×132=221×R2 +F1 ×312

312(F2 –F1) = 110378 (F2 –F1)=340 R1=55N R2 =1150N (F2 –F1)=340N

The capable limiting friction is

μ (R1-R2) = 540N

⇒ Frictional forces are proportional

⇒ 345, 16.5 are frictional forces

Design of Ramp:

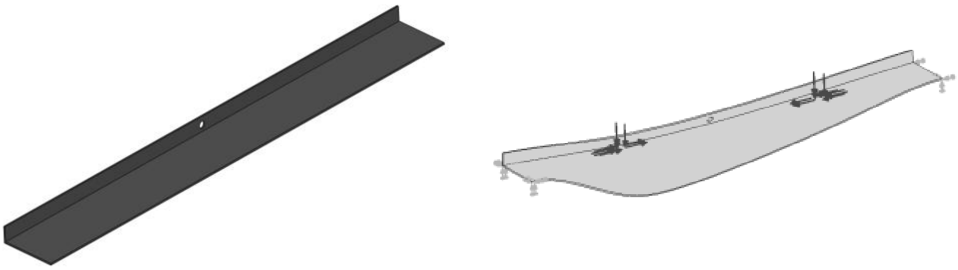

Fig. 3. Design of ramp

Design of Ramp and Mechanical Stops

The ramp simulation is carried out in Solid works .The forces on the ramp are calculated manually by calculation. The ramp thickness is made to produce a safe design. The telescopic rods are supposed to be made with aluminium alloy so that the weight of rods and ramp will not hinder the ease movement manually. Based on these weight ratios mechanical stop are designed manually.

Ramps (often multi-fold or telescopic) slide into a dedicated compartment directly beneath the seat, attached to the frame, or along the side members of the wheelchair. Usually foldable (multiple sections) or telescopic/sliding to fit the available space. They might be permanently attached to the frame at one end or detachable for easier deployment. Ramps (often split into two narrower sections) clip or mount securely to the outside of the wheelchair frame, along the armrests, or rear uprights.

The dimensions are given to suit the design and the thickness has to be calculated.

Ramp width = 4in

Ramp length = 32in

Ramp side projections width = 1in

Ram = Aluminum

Reaction force between the rear wheel and the rim R1 = 55N

Reaction force between the front wheel and the rim R2 = 1150N

Friction force between the rear wheel and the rim F1 = 16.5

Friction force between the front wheel and the rim F2 = 345N

Designing Mechanical Stops

These stops are used for resting ramps in backward direction during normal manure

Torque at stop = 0.386×9.81×.922 +.283×9.81×.543 = 4.99 N-m

Lets F.S be 1.5

4.99×2 = 9.98

So this torque acts on the for simulation purpose Rod extension length150mm or .150m

The torque = 116.588 N-m => The force applied on rod will be 777 N

The proposed wheelchair design incorporates simple, low-cost attachments that enable a user to independently negotiate roadside curbs and small level differences commonly encountered in household and urban environments as shown in figure.4. Unlike existing solutions that rely on complex mechanisms, high-power actuators, or expensive control systems, this design emphasizes manual operability, affordability, and practicality. The attachments are mounted with a slight eccentricity to the main axle, allowing the occupant to deploy and reposition them with minimal effort while seated. During operation, the attachments function as a temporary ramp, redistributing loads and reducing the force required to overcome the curb height. Mechanical stops are integrated to arrest the attachments at predefined positions, eliminating the need for removal and ensuring safety and repeatability. Force analysis on the ramp during wheelchair traversal guides the structural design, ensuring adequate strength while maintaining lightweight construction. Overall, the design provides an economical and user-friendly solution that enhances mobility and independence for wheelchair users without compromising simplicity or cost.

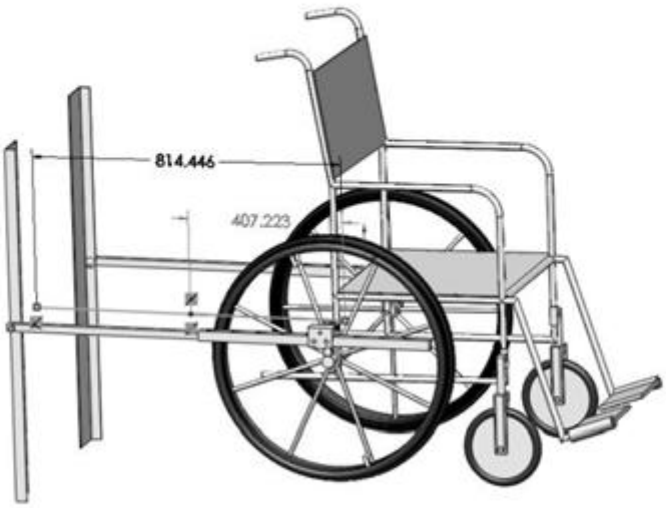

Fig.4. Wheel chair with attachments

Limiting Condition for Torque on Stops Simulation shows that use of steel material for designing of mechanical stops produces safe design. The simulation was carried out by adding a rod which can produce same torque on the stop.

Stress Analysis of Wheelchair

Stress analysis of the wheelchair was carried out using ANSYS Workbench to evaluate the structural safety and load-carrying capability of the frame and curb-climbing ramp attachments under realistic operating conditions. A three-dimensional CAD model of the wheelchair assembly, including the main frame, wheels, and ramp attachments, was imported into ANSYS for static structural analysis as shown in figure 5. The material properties corresponding to the selected materials (typically aluminum alloy for the ramp and steel/aluminum for the frame) were assigned, including Young's modulus, Poisson's ratio, and yield strength.

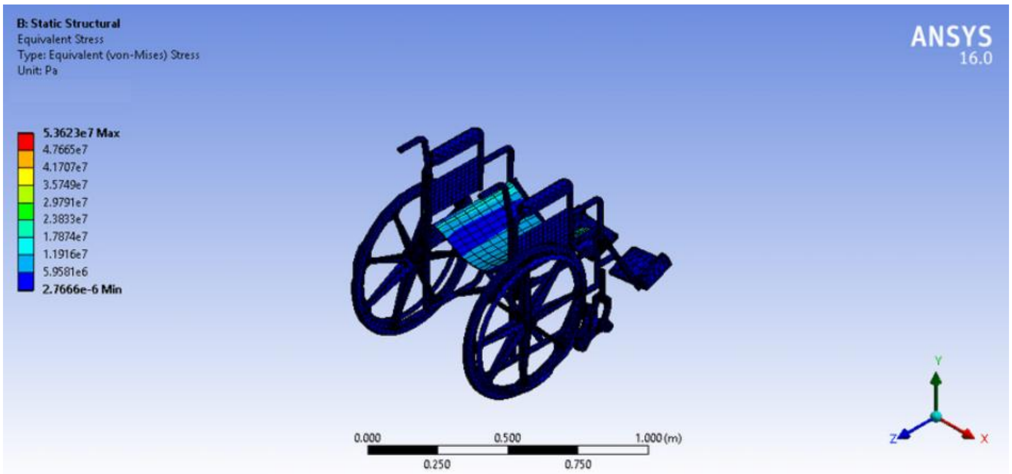

Fig.5. Analysis of wheel chair using Ansys

Boundary conditions were applied to simulate actual usage. The wheel ground contact regions were constrained appropriately to represent support from the ground, while external loads were applied at critical locations such as the seat region and wheel ramp contact points. Reaction forces obtained from theoretical calculations (R_1, R_2) and friction forces (F_1, F_2) were applied to represent the wheelchair negotiating a curb using the attachment. For the mechanical stop, the equivalent force of 777 N derived from torque calculations was applied at the rod end to simulate worst-case loading with the chosen factor of safety.

The model was discretized using an adequate mesh, with finer mesh refinement at stress-concentration regions such as joints, ramp edges, axle connections, and mechanical stops. The solution provided results in terms of total deformation, von Mises stress, and

equivalent elastic strain. The von Mises stress distribution was used as the primary failure criterion, as it is suitable for ductile materials. The results showed that the maximum stresses occurred near the front wheel ramp contact region and at the mechanical stop interface, while the remaining regions experienced relatively low stress levels.
The maximum von Mises stress obtained from ANSYS was found to be below the yield strength of the material, indicating that the design is structurally safe under the applied loading conditions. The deformation values were within acceptable limits, ensuring user comfort and functional stability during curb climbing. Overall, the ANSYS stress analysis validates that the proposed wheelchair with attachments can safely withstand operational loads, and it also helps identify critical regions for possible design optimization and weight reduction.

Results and Discussion

Based on the given dimensions and loading conditions, the aluminum ramp and mechanical stop system were evaluated for structural adequacy and safe operation. The ramp, with a width of 4 in, length of 32 in, and side projections of 1 in, is subjected to reaction forces of 55 N at the rear wheel (R1) and 1150 N at the front wheel (R2), indicating that the front wheel ramp interaction governs the design. Corresponding friction forces of 16.5 N (rear) and 345 N (front) further confirm that the maximum stresses and bending effects occur near the front contact region. These forces were used as the primary inputs for thickness calculation to ensure the ramp can withstand bending and shear without yielding, considering aluminum's favorable strength-to-weight ratio.
For the mechanical stops, the calculated torque acting during backward resting of the ramps is 4.99 N·m. Applying a factor of safety of 1.5, the design torque increases to approximately 9.98 N·m, ensuring reliable operation under uncertain loading and user-induced variations. For simulation purposes, when this torque is transferred through a rod extension length of 150 mm, the equivalent torque demand was evaluated as 116.588 N·m, resulting in an applied force of approximately 777 N on the rod. This force value was used as the critical load in structural simulation of the stop mechanism. The results indicate that the mechanical stops and rod must be designed to safely withstand this force without excessive deformation or failure. Overall, the analysis demonstrates that the ramp thickness and stop mechanism, when designed using these conservative loads, will provide safe, stable, and repeatable performance while maintaining simplicity and low cost, aligning with the objective of an affordable curb-climbing wheelchair attachment.

Conclusions

The wheelchair design was successfully completed with the integration of ramp attachments and telescopic rods, with a strong emphasis on optimizing the system to suit users of varying physical abilities. Mechanical stops were designed based on limiting and worst-case loading conditions to ensure reliable and safe operation during deployment and retraction of the ramps. A detailed motion analysis was carried out by evaluating each intermediate position of the mechanism, and the sequence of movement was illustrated through individual frames to verify smooth and interference-free operation. Several design refinements were implemented to improve usability and safety. These included introducing a controlled eccentricity at the telescopic rod connections to reduce the effort required for manual operation, as well as modifications to the basic wheelchair structure such as improvements in front wheel mounting to enhance stability during curb negotiation. Structural and motion simulations conducted in SolidWorks provided quantitative evidence that stresses, deformations, and kinematic behavior remain within acceptable limits, confirming that the proposed design is structurally safe and functionally reliable. Ensuring user safety and ease of use was treated as a critical design objective throughout the development process. From an accessibility perspective, the ramp geometry was selected to minimize user effort. Longer ramps result in shallower slopes, which significantly reduce the force required for ascent and descent, particularly for manual wheelchair users or individuals with limited upper-body strength. This approach is consistent with widely accepted accessibility principles, such as the 1:12 slope guideline recommended in international standards. The primary advantage of the proposed design is its ability to improve independent mobility, enabling users to negotiate curbs, small steps, and vehicle entry points without external assistance or specialized infrastructure. The use of lightweight materials, such as aluminum or composite alternatives, further enhances portability and ease of handling, while non-slip ramp surfaces improve safety during operation. Overall, the design significantly enhances accessibility, independence, and confidence for wheelchair users across a wide range of everyday environments.

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