# STUDY OF RELATION BETWEEN WHEELCHAIR ERGONOMICS WITH ITS ENVIRONMENT AND MATHEMATICAL MODELLING OF LEGGED WHEEL

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**Abstract**

**Population of India is 16.58% of total world population, with population explosion disability is also a serious issue. As per census-2011, 2.21% of total population is disabled and out of that 70% are from rural areas [01]. As per WHO, 15% world population is disabled and an India accounts for 2.44% of world. Last century has seen many technological advances, however with regard to mobility assistance no major changes have occurred. As India is stepping from developing country to developed country, it should focus on development at social level, fair living conditions and mobility for disabled and aged people at public and religious places. Freedom while functioning optimally in the environment consisting many barriers both man-made and natural depends on consideration of this factor while designing the wheelchair. This paper focus on relation between wheelchairs ergonomic with its environment and Mathematical modelling of proposed legged wheel over stairs to find out behaviours of wheel and various forces over it.**

**Index Terms: disability, population explosion, wheelchair ergonomics, legged wheel.**

## I. INTRODUCTION

Around 2 million wheelchairs are used in U.S in 2000, [02]. Also in India ALMICO sale around 26000 wheelchair still 2010 and each year it sold around 100 to 150 units. People with physical disabilities either due to chronic sickness or aging or by birth disability has to spend remaining time of life in a seated posture or restricted to wheelchairs. Due to their physical difference with the non-disabled, the physical access issue and the lack of consideration of these people while designing public transportation facility, their participation in daily activity and communication is usually obstructed. Even the daily living activities, such as dressing and undressing, are difficult for the disabled and are required to seek the help of others family members. For those stroke survivors who use wheelchairs, dressing and bathing are the most common self-care problems for them. As these people are dependent on other people for their functioning in the environment, they have inferior complex of disability. In order to provide freedom and perform day to day activity freely without any barriers in their functioning in the environment, study of wheelchair ergonomic and its relation with its environment is important.

## II. Environment Inspection [04]:

The physical environment in which person has to function consists of variety of both man-made and natural objects. Man-made objects refer to buildings and structures created and natural objects include other human as well as geographical objects such as plants, mountains, rivers, uneven terrain, and so on. The environment consist of extensive range of components that impacts human function and includes the individual's home, neighbourhood, Twisting causes shear stress. Community, and methods of transportation, in addition to the individual's educational, workplace, entertainment, commercial, and natural settings.

Environmental barriers are defined as physical obstructions that prevent individuals from functioning optimally and safely in their own environment which include safety, hazards, access problems, and home or workplace design difficulties. Accessibility is the degree to which an environment affords use of its resources with respect to an individual's level of functions. Accessible design typically refers to structures that fulfil required standards for accessibility. In the United States, these standards are available from the American national standards institute the fair housing amendments act of 1988 and the uniform federal accessibility standards. Requirements for public and commercial buildings are regulated by the accessibility guidelines of the Americans with disabilities Act. Universal design refers to the design of product and environments to be usable by all people to the greatest degree as possible, without the need for conversion or dedicated design. The design concept highlights on social inclusion by creating environments that are usable by individuals of different ages. Stature, sizes and abilities as well as addresses the changing needs of human being across the life span. Although universal design is both accessible and free of obstacles, it is not the same as bringing existing building or structure into compliance with ADA standards for accessible design or other building codes or laws. Applying such standards to existing structures often results in important but selective accessibility. While studying the environment of wheelchair in which it functions, it can be classified in to two parts as exterior accessibility and interior accessibility.

### *1:* Exterior accessibility:

Exterior accessibility includes consideration of rout of entry and entrance. Route of entry:

While designing entry route major consideration must be given to the wheelchair bound patient. Following are some key rules for same.

1) If there is more than one entry to the house then most convenient and safe should be selected. 2) The driveway should be smooth, level surface with easy access to the home. Walking surface to entrance should be carefully designed. 3) The entrance should be levelled, well lighted, and provide adequate cover from adverse weather condition. 4) Ideally step should not be more than 180 mm high and 280 mm in width. Step should be provided with nonslip surface to improve traction.5) handrails should be installed, where ever it needed. In general handrail height should measure between a minimum of 865 mm and a maximum of 965 mm high. At least one handrail must be extending a minimum of 305 mm beyond the foot and top of the stairs. Outside diameter of circular handrails should be between 32 to 51 mm. 6) ramp grades for wheelchair ramp is that for every inch of beginning height there is corresponds to 305 mm of ramp length. The overall rise of any ramp should not be more than 760 mm. handrails also should be included on the ramp with minimum height of 965 mm and extend 305 mm beyond the top and bottom of the ramp.

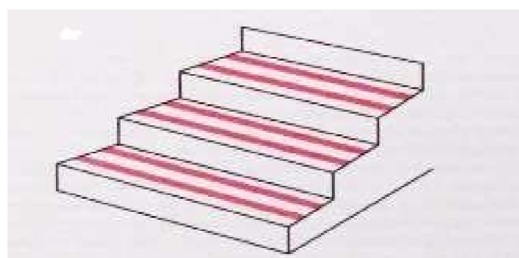


**Fig. 1. Abrasive strip on step to improve traction [04].**

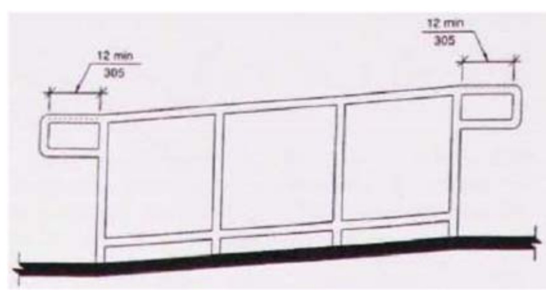



**Fig. 2.handrails extensions standard [04].**

Entrance:

The entrance should have platform large enough allowing patient to rest and make ready for entry. This platform area is mostly important when a ramp is in use. It provide for safe movement from the inclined surface to the level surface. If a person using a wheelchair is wanted to open a door that swings out, this area should be at least 153X153 cm. if the door open away from the patient, a space at least 91.5cm deep and 153cm wide is required. The door lock should be easily accessible to the patient. The height of the locks should be determined as well as the amount required to open the door should be as minimum as possible. The door should open and close in a direction that is handy for the patient. The door way width should be measured. Generally 815 to 865 mm is an acceptable doorway width to accommodate most wheelchairs. The pressure required should not open exceed 8 pounds to be functional for the patient.

***2:* Interior accessibility:**

Interior accessibility includes the design rules for wheelchair bound patient especially for arrangement of furniture, floors, door, and stairs.

Arrangement of furniture:

Sufficient carpet area should be made available or manoeuvring a wheelchair and or with an assistive device. In an initial stage move as much as possible furniture against the wall to increase clearance and stability. More stability can be achieved by placing rubber suction cups under the legs of sofas and chairs. Clear passage must be allowed from one room to the next room.

Floor:

Floor should be nonslip and well levelled. All floor coverings should be glued or attached to the floor. This provides protection from gathering or ripping under wheelchair use. When carpeting is used, a dense, low pile, low- level loop generally provides for easiest movement of a wheelchair and or ambulatory assistive device. Scatter rugs should be removed. Large area rugs can be secured with a good quality carpet tap. Use of non-skid waxes should be encouraged.

Doors:

Raised edges should be removed to provide a flush level surface. If structural elements prevent removal, thresholds ramps can be easily installed. Doorways may be widened to provide clearance for a wheelchair and or assistive device. Removal of wood strips on the inside of the door frame will add approximately 19 to 25.4 mm of clearance.

Stairs:

All indoor staircases must be provided with handrails and should be well-lighted. Ideally handrails should extend a minimum of 305 mm past the top and bottom of the stairs for additional safety. Stair should be free of clutter. Rather than climbing the stairs to move a single item to the next level. Contrasting colour tap on the border of each stair should be provided in order to having benefit of visual impairment.

## III. Ergonomics of wheelchair [04]:

A wheelchair is a combination of postural support system and a mobility base that are combined to create dynamic seated environment. Postural support system is made up of surfaces that contact with patients body directly. It includes the seat, back and foot support system. As well as additional components are required to maintain postural alignment. Mobility base consisting tubular frame, armrest, foot support and wheels, i.e. system providing drive for wheelchair. In addition it consists of auxiliary support system such as head support system, lateral support system for trunk, hips and knees.

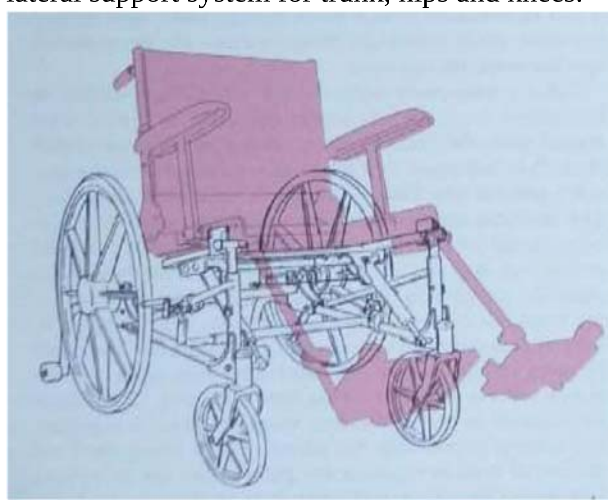


**Fig. 3. Wheel-chair combination of postural support system and mobility base [04].**

***1:* Postural support system:**

The components of the system that will directly effect on comfort and proper maintenance of posture are mainly seat surface, back surface pelvic belt, and upper extremity and lover extremity supports. These areas should be addressed combine as the postural support system. Increased contact between the user and the support surfaces increases comfort and control and decreases pressure over bony prominences. The series of available support system goes from firm planer surfaces, through deformable surfaces and contoured surfaces, up to and including customer molded surfaces.

Seat surface:

Many wheelchairs are available with a fabric or sling seat. This type of surface causes a poor pelvic position because the hips tend to slide forward, creating a posterior pelvic tilt. The thighs typically move toward adduction and internal rotation, and the patient tends to sit unevenly. Most wheelchair users can get advantage from a firm sitting surface. The depth of the seat should be measured carefully, because an overly deep seat will create pressure behind the knee and encourage a posterior pelvic tilt and a resultant tendency toward kyphotic posturing. A seat that is too narrow will not provide enough support making maintenance of LE alignment more difficult.

Back surface:

Individuals using a wheelchair who have reasonable good trunk control usually require only back support to the mid-scapula. Many prefer it lower. Some sit well with just the upholstery in place while others require additional support in front of or instead of the upholstery. Although some low wheelchair-Backs work well in the short run; they may cause problems over longer periods of use, with users facing fatigue and back pain. In these cases, a higher back is more suitable. In most cases, the standard fabric back that comes with a wheelchair does not provide adequate support for long periods of sitting. Some wheelchairs are available with back upholstery that has reinforcing straps that can be adjusted to provide contoured supports. A higher back may make it more difficult for caregivers to adjust posture, but the added control offered will decrease the need for frequent postural alterations. It is very important to create the correct seat/back angle for confortable postural alignment of the head over the shoulder and pelvis.

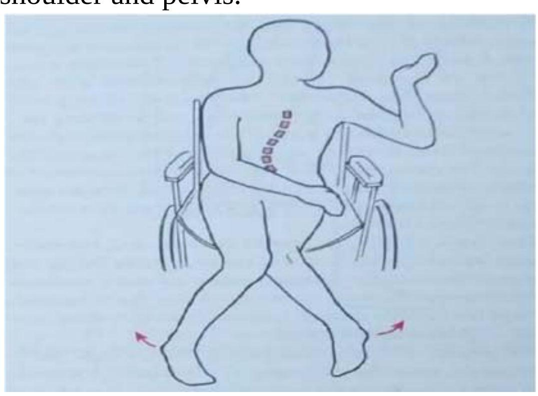


**Fig. 4. Poor setting posture due to sling seat [04].**

Seat Depth:

Correct seat depth is mainly important to achieve maximum postural support and control. Seat depth corresponds to the depth of the upholstery or seat itself from back to front edge. The upholstery or seat depth may be equal to, less than, or greater than that of the metal seat rail.

Seat width:

The width of seat, as well as overall width of wheelchair is important to functional use. Special consideration is required for person who wears orthosis, requires control blocks at the hip or lateral thigh/knee, wear bulky clothing, or experience weight fluctuations. The overall width of wheelchair should be as narrow as possible for optimal function. Available seat width can be changed in several ways, such as 1) use of fixed offset or removable arms, 2) use of attachable armrest receivers 3) construction design of new chair 4) changing or adjusting bottom cross braces on an existing wheelchair.

Seat height:

The wheelchair's seat height is measured from the seat rail to the floor with the chair fully opened. Seat Height is important parameter for optimal independent functioning in foot-assisted self-propulsion, transfer, ground clearance under the footplates on various terrains, approaching working surfaces interacting with peers and transferring into a van with lift or ramp. Seat height can be changed by implanting one of following options 1) altering frame construction, 2) changing wheel size 3) altering rear axle and front caster placement on frame 4) altering thickness of seat inserts and cushions.

Pelvic positioner:

A belt or more rigid pelvic positioner may be needed for safety and for assistance with postural control. Padding is suggested it the belt is pulled tightly to influence or maintain pelvic alignment. The direction, angle of pull and number of anchor pints of the belts is important. The angle of pull to the seating surface should be normally $45^0$ to $60^0$.

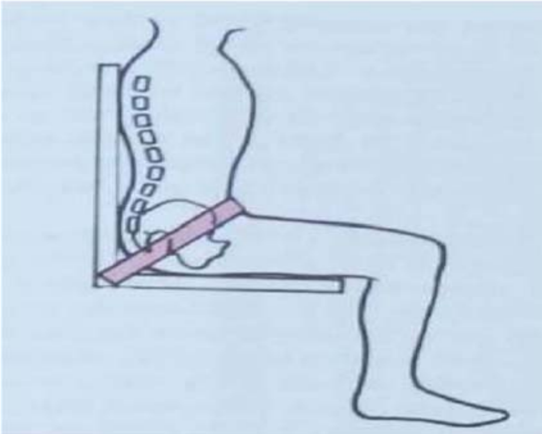


**Fig. 6. The pelvic belt should cross the pelvic-femoral at approximately a $45^0$ to $60^0$ to seating surface [04].**

Upper extremity support:

Wheelchair armrests have many important functions. They provide assistance for pushing up to standing, a support surface for arms and UE support surfaces such as to boards a mechanism for relief of ischial pressure and some small amount of lateral stability. Attention should be focused to the height of the armrests, and the length and size of the support surface, it may be necessary for the patient to use the armrests to support the UE and thus decrease pull on the shoulders and trunk, which may also affect head position. For some patient armrest will be used to mount an upper extremity support surface such as a tray or trough. These surfaces provide numerous vital functions. In addition, in special cases, high upper extremity support surface can be used to inhibit tone around the shoulders and neck. Lower extremity support:

Style and position are important concerns when selecting foot support systems. Placement of the foot support system will directly affect the position of the enter lover body, affecting tone and posture in the trunk, head, and arms. Adequate hip flexion will help keeps the pelvis well positioned on the sitting surface. Good foot support height and style are required for maintenance of this position. Foot supports that are too low will results in lower knees, placing the hips in more open angle and encouraging forward sliding of the pelvic. Foot supports that are too high may unload the thighs, placing increased weight on the ischial tuberosities. Elevating leg rests even in their lowered positions may be place excessive stretch on tight hamstrings, pulling the pelvic into a posterior tilt.

***2:*** **The wheeled mobility base**

The wheeled base forms the mobility structure for the seating system. Mobility bases include dependent systems and independent systems. Independent systems activated manually, and independent systems activated under battery power. Dependent systems include strollers, pushchairs and many of the elaborate postural support system used by individuals with severe disability and mental impairments. This system may have small wheels that are not planned for self-propulsion. When considering a dependent mobility system it is important to determine the function of the unit. If the ability to use any independent movement system exits the person should be considered for either a manual or powered wheelchair as the primary mobility system.

When considering a manual self-propelled mobility base, it is serious to consider the possible implications for long term function of the shoulder gridle. Research indicates that patients that use manual wheelchairs, especially if they are not properly fitted to their bodies and functioned are in danger of UE damage from repetitive strain injuries. Ideal self-propped wheelchair should be like as follows, 1) Has lightest weight possible.

2) Has a most stable frame for efficient movement.
3) Is well-manufactured, with high-quality bearing for less roll resistance when push forces are applied, and secure non-moving parts.
4) Has optimal wheel size and type for individual patient function.
5) Provide the best possible combination of ease of propulsion and stability.

Careful consideration should be directed toward the patient's position in the chair. The pelvic should be in a neutral position with trunk upright. The spine should be extended slightly over the pelvic into a ready posture for pushing. It may be necessary to open the seat/back angle to achieve this for some patients. The trunk and hips should be stable to allow full release of the UE for wheel approach and push. If the patient does not have trunk stability it may be necessary to provide additional external supports.

## IV. Mathematical modelling of legged wheel

**Figure.no.07 Human legs posture and mathematical relation while climbing up stairs.**

In India though number disability in movement is around 54.36 lakh, There is also provision in law mentioning there should ramps near stairs at public places to assist wheelchair bound patient. Yet barrier free design is not given as much as important as required. So to provide solution to this problem new wheel geometry is proposed which will act as wheels for wheelchair over stairs and help in climbing the stairs. The legged wheel design is inspired from human. That is the leg posture made by human being while climbing the stairs. When human start climbing the stairs, left leg on previous step and right leg on next steps as shown in figure, during this posture the angle between two legs is for average height person is $40^0$. Hence by taking this reference legged wheel geometry is proposed. Such that making angular arrangement by keeping angle between each legged wheel as $40^0$, it wheel helps wheelchair in climbing stairs same as human being. However before designing actual wheel it is necessary to calculate various forces acting on legged wheel over stair. Before determining forces on legged wheel, various forces acting over wheelchair is as follows,

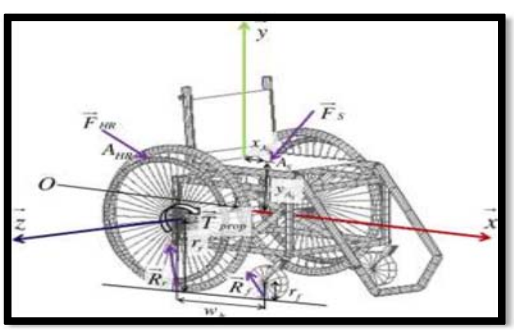



**Figure.no.08 Free Body Diagram of Forces Exerted on the Wheelchair during Propulsion[05]**

Above figure show various forces acting over wheelchair over flat surface effect of rolling resistance with ground reaction and force applied by patient over wheel is considered. By resolving various forces we came to final equation for ground reaction and front and rear wheel as follows[05],

$$R_{Nr} = -(W_{wc} + F_{sy} + F_{HRy} + R_{Nf})$$

And

$$R_{Nf} = \frac{[y_{As}F_{Sx} - X_{As}F_{Sy} - T_{Sz}] - X_G W_{WC} - \left(M y_G + (r_f - r_r)\frac{I_f}{r_f^2}\right)\alpha}{\left(W_b + \frac{r_f - r_r}{r_f}\lambda_f\right)}$$

Thus applying same logic for legged wheel, with consideration of legged wheel is attached to wheelchair and wheelchair is being pushed from back over stairs, by resolving forces acting over legged wheel, reaction at leg on previous step and legged wheel on next step is as follows,

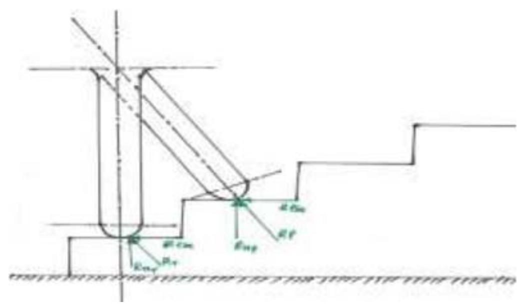
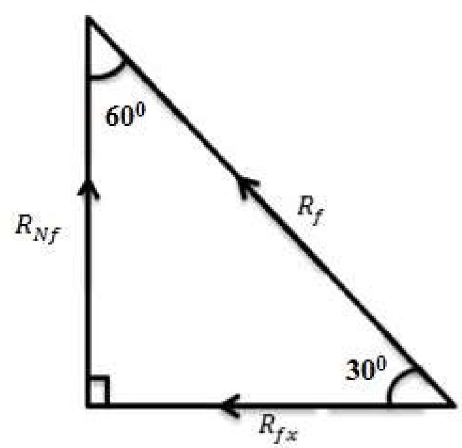


**Figure.no.09 force acting on front and rear leg wheel, resting on stairs**

Out of this two reaction acting over front and previous legged, reaction force acting over front leg can be resolved in to two components.




$$R_{Nf} = \sin 60 * R_f$$

And

$$R_{fx} = \cos 60 * R_f$$

Thus out of this two component sin compoent of that is $R_{Nf}$ is nothing but lifthing force which is need to be overcome during climbing up the stairs.

## V. Conclusions

After studying the various design parameters, and its role in optimal functioning of wheelchair in it environment, in order get optimal functioning following conclusion can be drawn.

1. Arrangement of furniture should made optimal to get more carpet area so wheelchair bound patient can move easily without any barriers.
2. Floor area should be such that it provides more traction. And doors must be easily accessible.
3. Seat depth, seat height and seat surface should provide optimal postural support to patients.
4. Mobility base should be such that it having optimal drive to wheelchair over all terrain, with minimum vibration and resistance to motion.

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