Vol. 7, No. 1, pp. 30-34, June 2008

INTERNATIONAL
JOURNAL OF SAFETY
www.kosos.or.kr

A Study on the Impact Safety Test for Wheelchairs

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(Received February 1, 2008; Accepted June 7, 2008)

Abstract : For the purpose of establishing basic design standards for the manufacture of wheelchairs, a dummy for an ISO-standard wheelchair was modeled for use with a manufactured wheelchair, and the safety and performance of the wheelchair were examined through numerical simulations.

Key words : safety test, wheelchair, mathematical model, disabled

1. Introduction

The development of industries has rapidly increased the number of people disabled from car accidents, aircraft accidents, and industrial accidents as well as congenitally malformed; and the development of medicine and the subsequent increase in the average life span has rapidly increased the number of people with weak, aging bodies. Many assistive devices are being produced for the increased social activity and convenience of the disabled. Crutches were developed for those who cannot walk due to a slight disorder or injury; wheelchairs were developed for the aged or those who cannot use both their legs, followed by electrical wheelchairs for greater moving convenience; and even technologies for artificial legs that facilitate walking in almost the same manner as that of normal people are being developed.

Among these assistive devices, diverse wheelchairs are being produced in developed countries following many tests and studies[1-12], and welfare facilities for the disabled are being constructed with provisions for wheelchair access. In Korea, most subway stations have wheelchair lifters or elevators for the welfare and convenience of the disabled. More researches must be conducted in Korea, however, on the development of better wheelchairs.

2. Experiment Method

The wheelchair that the authors' laboratory had earlier developed was mathematically modeled, and an ISO-standard dummy was made for it. Then using the dynamics analysis software ADAMS, the stability of the wheelchair and the effect of the application of weight and impact to the wheelchair were analyzed as the wheelchair was made to travel on a flat surface and a slope, to derive an optimal wheelchair design.

A method of determining the effect of dynamic weight on the wheelchair was developed by Vanderby and Patwardhan, who used the FE analysis program to make a wheelchair model and to analyze the standard wheelchair. In this study, a simulation was conducted with the modeled dummy on a wheelchair under the least stable and most stable conditions. As for the external environment, a 20±10°C temperature, a 65±30% humidity, a flat travel path, and a 0.6-1.0 friction coefficient were assumed.

1. Conditions for the Forward/Back/Side Static Stability Simulation The least stable direction and the most stable direction were defined in terms of the forward/back/side static stability, as shown in Tables 1, 2, and 3. Based on these two conditions, the simulation was conducted sequentially from a to f.

a. For the simulation with the wheels unlocked and the wheelchair in the least stable condition, each part of the wheelchair was set at the least stable condition. The wheelchair was placed on the flat surface, and the roll restraint and wedges were used to prevent it from rolling. The wheelchair stability was analyzed while the angle of the flat surface was increased.

b. For the simulation with the wheels locked and the wheelchair in the least stable condition, the front wheels were locked and flexible means were installed to pre-

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Table 1. External simulation conditions in the forward direction

Adjustable Wheelchair Component	Least Stable	Most Stable
Rear-wheel position	Forward	Backward
Castor attachment to frame	Backward	Forward
Seat position	Forward	Backward
Seat position, vertical	High	Low
Seat-back position	Forward	Backward
Seat-back position, reclined	Upright	Backward
Seat position, tilted	Upright	Backward
Elevated leg-rest position	Up	Down

Table 2. External simulation conditions in the backward direction

Adjustable Wheelchair Component	Least Stable	Most Stable
Rear-wheel position, camber	Narrowest track	Widest track
Castor attachment to frame	Backward	Forward
Castor attachment to frame, inside-outside	Inside	Outside
Seat position	Forward	Backward
Seat position, vertical	High	Low
Seat position, tilted	Upright	Backward
Seat-back position, reclined	Upright	Backward

Table 3. External simulation conditions in the side direction

Adjustable Wheelchair Component	Least Stable	Most Stable
Rear-wheel position	Forward	Backward
Castor attachment to frame	Backward	Forward
Seat position	Backward	Forward
Seat position, vertical	High	Low
Seat-back position, reclined	Backward	Upright
Seat position, tilted	Backward	Upright
Seat-back position	Backward	Forward

vent the slipping of the wheelchair. The simulation and the stability analysis were performed using the same method as that in the previous test.

c. For the simulation with the wheels unlocked and the wheelchair in the most stable condition, each part of the wheelchair was set at the most stable condition. The simulation and the stability analysis were performed using the same method.

d. For the simulation with the wheels locked and the wheelchair in the most stable condition, the test was conducted using the method in b.

e. For the simulation with the wheelchair in the least stable condition, each part of the wheelchair was set at the least stable condition. The wheelchair was placed on the test flat in such a manner that its rotation axis was parallel to the rotation axis of the flat ground. The wheels were locked, and the roll restraint and flexible means were used to prevent the wheelchair from slipping. The wheelchair's stability was analyzed while the angle of the test flat was increased.

f. For the simulation with the wheelchair in the most stable condition, each part of the wheelchair was set at the most stable condition. The simulation was performed using the aforementioned method.

2. Selection of the Test Model

The review of the dummy according to the domestic standards and the ISO standards showed that the domestic dummy standards are based on the international ISO standards. Therefore, the dummy in this study was based on the ISO-defined dummy. A dummy made up of an upper half, a lower half, and legs was re-formed using the 3D modeling software Solid Works, with the four dummy models (100, 75, 50, and 25kgf) presented in the ISO standards. The materials were modeled according to the standard specifications, including the use of plywood for the body frame and a steel plate for the balance weight. Each component was manufactured to satisfy the error range of the physical properties of the materials as presented in the standard specifications. The barycenter on the drawing and the barycenter in the manufacturing process were compared, and the difference fell within the error range.

Fig. 1 shows the dummy on the wheelchair on the flat ground. The dummy on the wheelchair was an ISO-standard 75kgf dummy with legs. With the broad flat plate as the ground, in-plane joints were used to restrain the front and rear wheels from rolling, and revolute joints were used between the front/rear wheels and the frame, and at the rotation axis of the front wheel, to allow them to rotate. The dummy was fixed on the wheelchair frame with fixed joints to prevent its separation from the wheelchair with the wheelchair's movement.

The dummy body and the balance weight were also fixed with fixed joints. Based on the prototype proposed in the major project, the rear wheel diameter was 60cm, and the front wheel diameter was 20cm. To make a lightweight wheelchair, 20mm-diameter aluminum pipes were used for the wheelchair frame, and the distance between the centers of the front and rear wheels was 45cm.

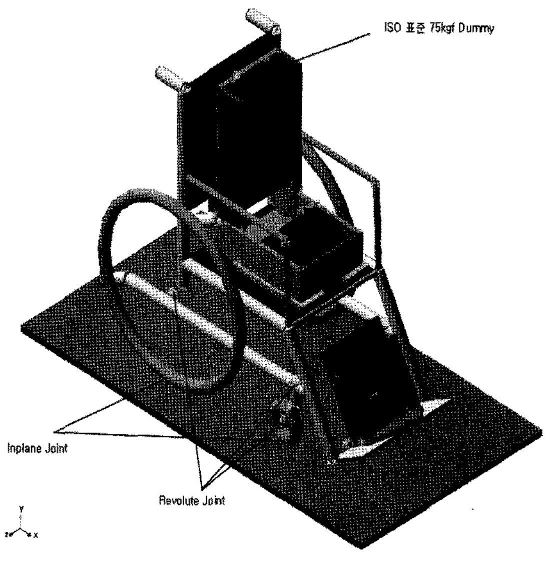

Fig. 1. Structure diagram of the wheelchair

3. Results and Analysis

3.1. Analysis of the Stability of the Wheelchair on the Flat

a. When a disabled person directly drives the wheelchair Assuming that a disabled person was driving the wheelchair by holding the wheelchair's rims and applying a force of 100N to it for 5 seconds, Fig. 2 shows the the speed and force diagrams according to the time lapse for the rear rotation axis in the moving direction. When the wheelchair was driven with a force of 100N on both its rims, it first moved forward smoothly, but after 2.5 seconds, it rocked slightly from side to side, showing a sudden diffuse distribution.

b. When a carer pushes the wheelchair (motion analysis according to the handle height) The motion of the wheelchair was observed when a force of 100N was applied to the wheelchair at a height of 100cm from the ground in the forward direction. The speed of the wheelchair and the weight applied to the wheelchair are shown in Fig 3.

The wheelchair speed and force did not vary according to the height of the handle. Thus, the height of the

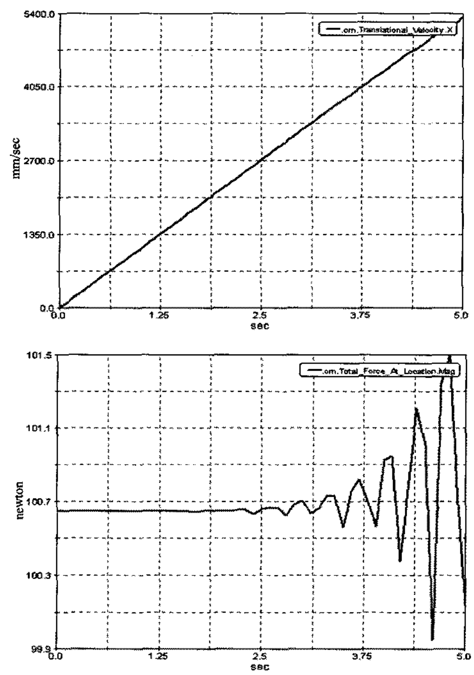

Fig. 2. Speed and force at the rear rotation axis when the weight was applied for 5 seconds to both wheels.

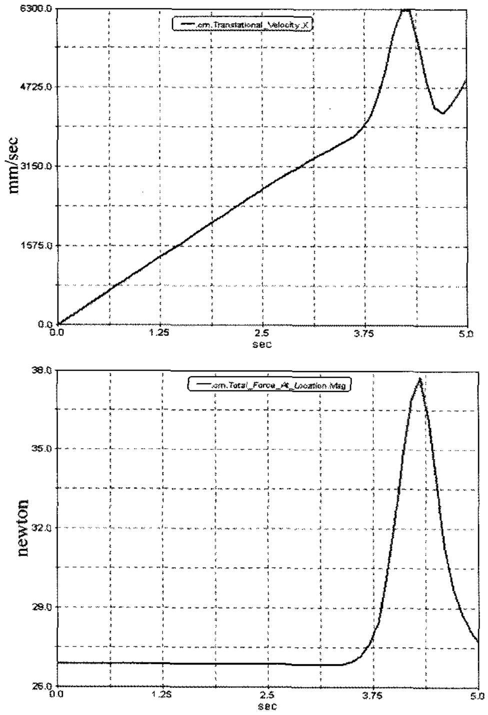

Fig. 3. Speed and force when the force was applied at a height of 1 m from the ground.

handle did not turn out to be a major factor of the wheelchair's speed and force. Accordingly, it seems that the height of the back should be dictated by the convenience of the patient, and the handle height should be dictated by the handling ease of the carer. In addition, the analysis of the wheelchair motion and the change in the force applied to the wheel when a disabled person drove the wheelchair on flat ground and when a carer pushed it showed that more force was delivered when a disabled person drove the wheelchair than when a carer pushed it. The wheelchair was manufactured in such a manner that each component could be disassembled and firmly reassembled. The components thus had to be firmly and easily installed because only some parts could be removed. Accordingly, the rocking and stability of the wheelchair was observed by applying force to each of its components, such as its armrest, footrest, and hand rim, but no significant change was observed because the components were connected with ideal joints and no tolerance or clearance was considered, which would have existed in an actual wheelchair. Thus, to check the test results fully, the durability and deformation of an actual model of the wheelchair must be tested on flat ground.

3.2. Analysis of the Stability of the Wheelchair on a 15° Slope

a. Climbing ability of the wheelchair To find the minimum driving force for the wheelchair to be driven on a slope (Fig. 4), the motion of the wheelchair was observed while the force was increased by 20-N increments to 100 N, and by 10-N increments to 300N. The wheelchair started to climb the slope when a 370-N force was applied. A minimum of 370N was required for the wheelchair to stand still on the slope. In addition to the wheelchair weight, the revolute joint between the frame and the wheel needed more weight due to the frictional loss. The braking power that the wheelchair needed for it to be able to climb the 15° slope was determined.

b.When sudden braking power is applied to the right wheel during a free fall.

A wheelchair moves at a uniform acceleration on a slope. The change in the motion of the wheelchair when braking power was applied to one side of it was shown via the moving distance, speed, and force of both of its wheel centers.

The results reveal the motion of the wheelchair when a sudden weight was applied only to its right wheel when it was freely moving. Its movement increased and stopped at 2.5 seconds, which means it overturned. The force at both its wheels was mainly applied to the braking side, and hardly any weight was applied to the wheel at the other side. Therefore, there is a high risk that the wheelchair may turn with the braked wheel as the center, lose its balance, and overturn.

4. Conclusion

In this study, the stability of wheelchairs was tested on a flat ground and a slope by preparing a prototype wheelchair and an ISO-standard dummy using the dynamics simulation software ADAMS, and the weight and torque applied to each component of the wheelchair were analyzed. Moreover, the braking power required for the wheelchair to stand still on a slope was estimated by analyzing the power required for it to be driven on a slope and on flat ground. It seems that the data from the analysis of these simulations can be used in a comparative analysis of manufactured wheelchairs, and thereafter, in the realization of the optimal wheelchair design.

This study assumed theoretical values for the simulation, although there are many variations in the actual environment. Those various factors had to be applied to the simulation for the conduct of the detailed analysis.

The wheelchair must be manufactured in correspondence with different types of handicaps, including for physically weak patients, patients with limbs amputated due to an accident, paraplegic patients, etc. For the patient to get on and off the wheelchair, assembly and disassembly of the wheelchair components must be easy.

The barycenter of the wheelchair will move slightly forward in the upward direction when the person on the wheelchair bends forward, and slightly backward in the downward direction when the person leans backward, instead of the barycenter remaining fixed in the direction of gravitational acceleration, as in this study. If the movement of the barycenter is applied to the simulation through an actual sample study, the applicability of the data will be increased.

The brake used in the wheelchair employed friction against the wheel. This method causes wear and tear at the bead of the wheel and reduces the straightness of the wheelchair motion. The stability of the wheelchair is significantly affected by frequent brakes when the motion is crooked. A further study must be conducted to reduce the wear and tear on the wheel by improving the wheelchair brake method.

Acknowledgement

This study was supported by Hansung University in the year of 2007

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