International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 5 Issue 11, November - 2021, Pages: 65-73

Design Analysis and Fabricaton of a Detachable Wheelchair

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Abstract: *This paper discusses the design analysis and fabrication of a detachable tricycle wheelchair which can be used by physically challenged people to go about their day to day activities in order to ease mobility and decrease the limitation of their movement. Investigation showed that that there are over 25 million Nigerians who suffer from one physical deformity or the other with over 3.5 million of them having difficult challenges of moving around due to inability to buy a wheelchair. The cost of the wheelchair produced is fifty-six thousand, seven hundred naira only (₦56,700) whereas the imported wheelchair costs about two hundred thousand and above (#200,000). In this work, the components of the tricycle were designed and selected according to standard specifications of the design model using CAD software and solid works simulations. Calculations carried out included stress analysis for the tricycle wheelchair and the input force required to move the wheel chair. The produced detachable wheelchair is made of round hollow galvanized steel pipe of* $\emptyset 28\ mm$ *and thickness of 2 mm was used for the construction of the wheelchair having dimension of 2000 mm × 600 mm × 1000 mm and a total weight of 24 kg. The pipes were bent and joined by welding to make the tricycle wheelchair. A performance test was carried out after the production – in terms of static and dynamic stability, maneuverability and pushing efficiency – which revealed it meets the design objective.*

Keywords: Physically challenge, Mobility, Deflection, Wheelchair, Shear Force, Pushing Efficiency, .Detachable Tricycle.

INTRODUCTION

Several people are dependent on manually propelled wheelchair for their mobility. In the Netherlands for example, approximately 82% of individuals with spinal cord injury (SCI) are wheelchair users (Post *et al*, 1997). A recent study shows that wheelchair mobility influences participation, peak aerobic performance output, and wheelchair skill performance, all of which are significant indicators of return to work for a group of wheelchair dependent persons with SCI, one year after discharge from inpatient rehabilitation (Van Velzen *et al*, 2009). In most developing countries, physically challenged people have been having difficulties over the years in moving around by themselves with a wheelchair, this requires an attendee in other for them to move about from point A to point B. Most times they get exhausted easily when trying to push or move the rims of the wheelchair by themselves. A hand tricycle wheelchair was introduced which is basically for conveying people that are physically challenged from one place to another with minimum effort .With the inability of most disabled people in Nigeria to buy the motorized wheelchair due to high cost and unavailability of electrical power for constant recharging of battery; the detachable wheelchair will be used as an alternative to the motorized wheel chair

A hand tricycle wheelchair works in the same way as a bicycle as it uses a chain system with pedals to drive the wheels. In the case of a hand tricycle, the chain is attached to the pedals, allowing the user much more efficient propulsion than would be provided from the push rims on a wheelchair. This paper therefore aimed at designing and fabricating a manually propelled tricycle wheelchair ideal for people with spinal cord injury and amputees.

MATERIALS AND METHODS

The design of this wheelchair involves calculating the shear force, bending moment, deflection. And the output and input force required to move the wheel chair

Components of the wheelchair

The galvanized steel pipe frame supports the structure for carrying the compartment were the user seats to control the tricycle. This support has a length of 500 mm and width of 40 mm and between these supports have some spacing , with an attachment to the four wheels, one at the front, one at the middle and two at the back. The vertical support of length 1mm which is connected to the handle (pedals) is welded to the horizontal frame of length 1.9 mm. The handle will be replaced by the pedals of a bicycle which will be transferred and mounted at the top of the long frame of the tricycle. The pedal serves as the controller as it turns 360°since the chain system is attached to the pedal to drive the wheels, allowing the user much more efficient propulsion.

The tricycle is equipped with four wheels (bicycle tyres) of hard rubber. One of the wheels is swiveled beneath middle side of the frame; it rotates 360° to support the other three wheels and the front wheel [Bicycle Tyres] that are fixed at the rear of the frame and at the front of the tricycle. The front wheel has a brake system and also a gear selector for easy movement of the tricycle. These wheels have sealed precision ball bearings with outer diameter of 125 mm and inner diameter of 75 mm.

The main tricycle wheelchair parameters and specifications are detailed and presented in Table 1, and also design analysis and calculation using solid-works simulation are detailed and presented in Table 2&3. Figure 1 shows the free body diagram of the bottom frame while Figure 2 and 3 show the shear force and the bending moment diagram. Also the pictorial and the isometric views are shown in Figure 4 and 5 respectively.

Design Analysis
Shear Force and Bending Moment

$M_{TRICYCLE}$ = 24kg × 9.81 = 235.44N

M_{LOAD} = 100kg × 9.81 = 981N

$\sum F^{+}$

$W = R_A + R_B$………………………......... (3.1)

$\sum M = 100 \times 9.81 \times 0.54 - R_B \times 2$

$R_B = \frac{100\times9.81\times0.54}{2}$

$R_B = 264.87N$

$W = R_A + R_B$

$R_A = W - R_B$ .... (3.2)

$R_A = 100 \times 9.81 - 264.87$

$R_A = 716.13N$

SHEAR FORCE

$SF_A = R_A = 716.13$

$SF_B = R_A = W$

$SF_B = 716.13 - 100 \times 9.81$

$SF_B = -264.87N$

$SF_C = R_A - W + R_B$

$SF_C = 716.13 - 100 \times 9.81 + 26 \times 4.87$

$SF_C = 0$

BENDING MOMENT (Figure 2)

$BM_A = 0$

$BM_B = R_A \times 0.54$

$BM_B = 716.13 \times 0.54$

$BM_B = 386.7102$

$BM_C = R_A \times 2 - W \times 1.46$

$BM_C = 716.13 \times 2 - 100 \times 9.81 \times 1.46$

$BM_C = 0$

MAXIMUM STRESS (Figure 3)

$\sigma_{max} = \frac{My_C}{I}$……………….. (3.3)

Where $I = \frac{\pi}{64}(D^4 - d^4)^2$

$I = \frac{3.142}{64}(26^4 - 22^4)^2$

$I = 5467.08mm^4$

$\mathrm{M} = 386.7102\mathrm{Nmm}$

$\mathrm{y_C} = 1.3\mathrm{mm}$

$\mathrm{I} = 5467.08\mathrm{mm}^4$

$$\sigma_{max} = \frac{386.7102 \times 10^3 \times 1.3}{5467.08}$$

$\sigma_{max} = 91.95\mathrm{N/mm}^2$

FACTOR OF SAFETY $Factor\ of\ Safety\ (n)$

$= \frac{Yield\ Strength}{\sigma_{max}}$……… (3.4)

$Yield\ Strength\ of\ Galvanized\ Steel = 203.943\ MPa$

$Factor\ of\ safety\ (n) = \frac{203.943}{91.95}$

$n = 2.218$

$n = 2.2$

STRAIN

$E = \frac{\sigma}{\varepsilon}$.................... (3.5)

$\varepsilon = \frac{\sigma}{E}$................ (3.6)

$where\ E = Modulus\ of\ Elasticity = 2 \times 10^6 MPa$

$$\varepsilon = \frac{91.95}{2 \times 10^6}$$

$\varepsilon = 4.5975 \times 10^{-5}$

Deflection Calculation

Now taking A as the origin and using Macaulay's method, the bending moment at any section X at a distance x from A

$R_A = 716.13$

$R_B = 264.87$

$\frac{\Delta L}{L} = \varepsilon$

$\Delta L = \varepsilon L$

$\Delta L = 2000 \times 4.5975 \times 10^{-5}$

$\mathrm{EI}\frac{\delta^2 y}{\delta x} = (\mathrm{R_A} \times \mathrm{x}) + \mathrm{W}(\mathrm{x} - 0.54) + \mathrm{R_B} \times 0$

Integrating the above equation

$$\mathrm{EI}\frac{\delta^2 y}{\delta x} = -716.13x + 981(x - 540)$$

Integrating both sides

$$\mathrm{EI}\frac{\delta y}{\delta x} = \frac{-716.13x^2}{2} + \frac{981x^2}{2} - 529740x + C_1$$

Integrating again

$$\mathrm{EI}y = \frac{716.13x^3}{6} + \frac{981x^3}{6} - \frac{529740x^2}{2} + C_1x + C_2$$

$$EIy = -119.555x^3 + 163.5x^3 - 264870x^2 + C_1x + C_2$$

We know that when x =0, then y=0 therefore

$$C_2 = 0$$

$$and\ x = 2000mm$$

$$y = 0$$

Therefore

$$0 = -119.355(2000)^3 + 163.5(2000)^3 - 264870(2000)^2 + C_1(2000)$$

$$-9.5484 \times 10^{11} + 1.308 \times 10^{12} + 1.05948 \times 10^{12} + 2000C_1 = 0$$

$$C_1 = \frac{7.05484 \times 10^{11}}{2000}$$

$$C_1 = 352920000$$

$$EIy == 119.355x^3 + 163.5x^3 - 264780x^2 + 3529200$$

Now deflection under the load at 0.54

$$EIy_C = -119.355(540)^3 + 352920000 \times 540$$

$$= -1.879411572 \times 10^{10} + 352920000 \times 540$$

$$EIy_C = 1.717828 \times 10^{11}$$

$$V_C \quad = \frac{1.717828 \times 10^{11}}{EI}$$

$$= \frac{1.71828 \times 10^{11}}{5467.08 \times 2 \times 10^6}$$

$$V_C \quad = 15.710mm$$

Input force required to move the tricycle

From gear train formula

$$\frac{r_B}{r_A} = \frac{N_B}{N_A} = \frac{\omega_A}{\omega_B} = \frac{\tau_B}{\tau_A} \ldots\ldots (1)$$

Considering

$\frac{r_B}{r_A} = \frac{\tau_B}{\tau_A}$…………….. (2)

$\boldsymbol{r_B}$ = Radius of the output sprocket
$\boldsymbol{r_A}$ = Radius of the input sprocket
$\boldsymbol{\tau_B}$ = Torque on the output sprocket
$\boldsymbol{\tau_A}$ = Torque on the input sprocket

Given data:

$\boldsymbol{r_B}$= 5cm = 0.05m
$\boldsymbol{r_A}$ = 10cm = 0.1m

M = 104kg

g = 9.81m/s^2

$\tau_B = F_B \times r_B$ …… (3)

F_B = M × g …… (4)

F_B = 104 × 9.81

F_B = 1020.24N

Therefore, F_B = 1020.24N is the output force.

Substituting F_B into equation (3)

τ_B = 1020.24 × 0.05

τ_B = 510.12Nm

From equation (2)

$\frac{510.12}{\tau_A} = \frac{0.05}{0.1}$

$\frac{510.12}{\tau_A}$= 0.5

$\boldsymbol{\tau_A} = \frac{510.12}{0.5}$

$\boldsymbol{\tau_A}$= 1020.24Nm

$\boldsymbol{\tau_A} = F_A \times r_A$…. (5)

1020.24 = F_A × 0.1

$F_A = \frac{1020.24}{0.1}$

F_A = 10202.4N

Therefore, the input force required to move the tricycle is
F_A = 102024N

MODE OF OPERATION

The tricycle wheelchair can withstand a maximum load of 104kg. The handle/pedal of the tricycle is held and rotates about 360° to start the movement of the tricycle to the destination of the user. When the tricycle needs to stop there is a brake connected to the front wheel since the front wheel is responsible for the movement of the tricycle. The brake handle that is attached to the frame is hold down to initiate the stoppage or reduce the speed of the tricycle.

RESULTS

The tricycle wheelchair was tested with a person sitting on it weighing about 80kg; the test was carried out repeatedly. From investigation, it was observed that each component functioned as expected. During the performance test Friction, Speed of movement, Vibration, maneuverability and Deflection were checked. There was no failure of components and all were found to be within acceptable limit. The performance test reveals that the tricycle wheelchair is very efficient. With a maximum load of 981 N/m; the input force required to move the tricycle is 102024N

CONCLUSION

The major aim of this paper was to design and fabricate a tricycle wheelchair for the physically challenged people with the ability to transport its user over an obstacle, such as curb, and to manufacture a cost effective wheelchair tricycle for easier accessibility and increased performance to the wheelchair user. The simple design makes it unnecessary for specialized skills in operation and maintenance. The minimum possible numbers of components were employed in the design to reduce complexity. The tricycle does not need recharging of battery because it is operated manually and it can serve as an alternative to the motorized wheel chair in terms of cost, maintenance and availability to many users. A detailed cost analysis is presented in Table 4.

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TABLES

Tables 1: Tricycle main parameters and specifications

S/N	ITEMS	SPECIFICATIONS
1	Length of Tricycle	2000mm
2`	Width of Tricycle	395mm
3	Height of Tricycle	1000mm
4	Wheelchair seat level from the frame	250mm
5	Weight of tricycle	24kg
6	Full length of galvanized steel pipe	5.515m
7	Thickness of the galvanized steel pipe	0.2mm
8	Plain rectangular mild steel plate	(2mm thickness; 4ft × 8ft)

International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 5 Issue 11, November - 2021, Pages: 65-73

Table 2: Solidworks simulation of the maximum stress

Name	Type	Min	Max
Stress	VON: von-misesStres	0 mm	7.2784e5

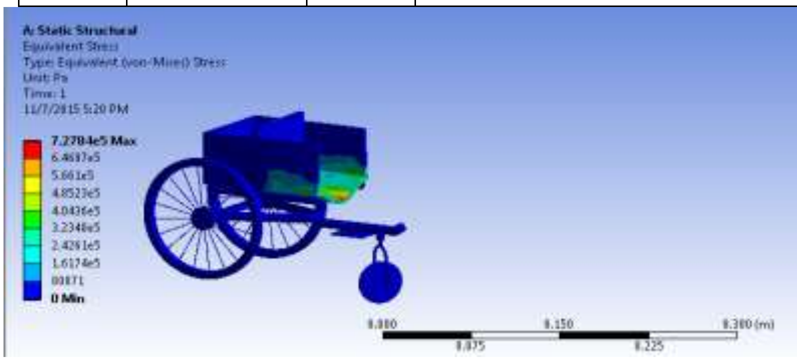
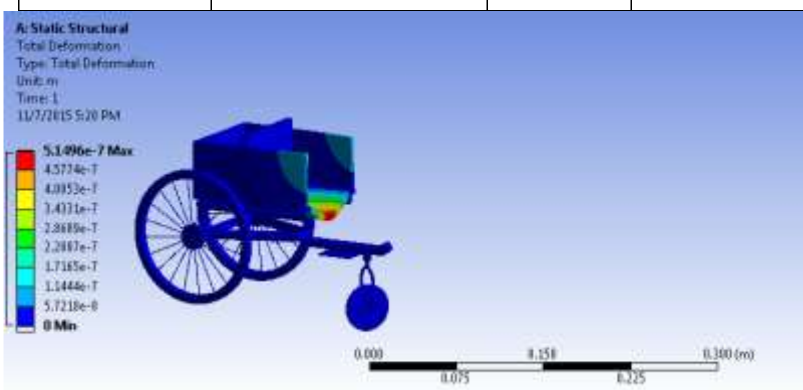
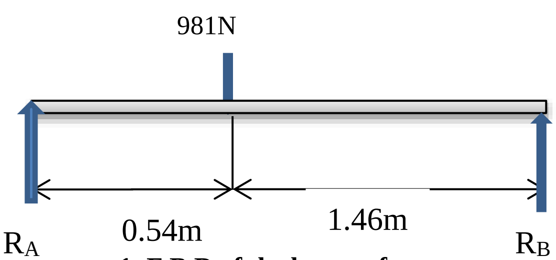


Table 3: Solidworks simulation of the total deformations

Name	Type	Min	Max
Deformation	Total Deformation	0 mm	5.1496e-7



FIGURES



ıre 1: **F.B.D.of the bottom frame**

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ISSN: 2643-640X
Vol. 5 Issue 11, November - 2021, Pages: 65-73

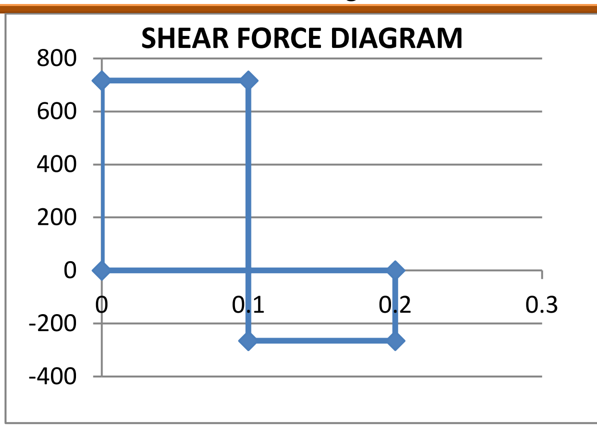

Figure 2: Share Force Diagram

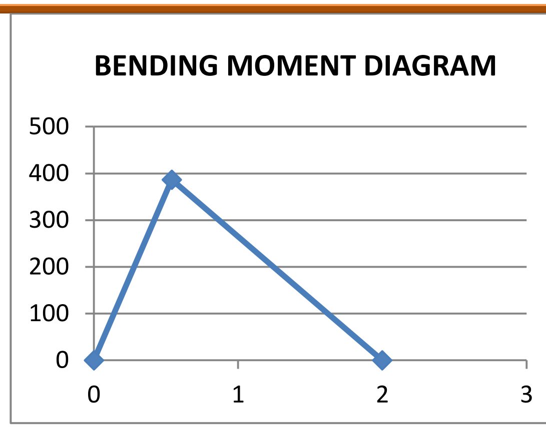

Figure 3: Bending Moment Diagram

Figure 4: Pictorial view of the wheel chair

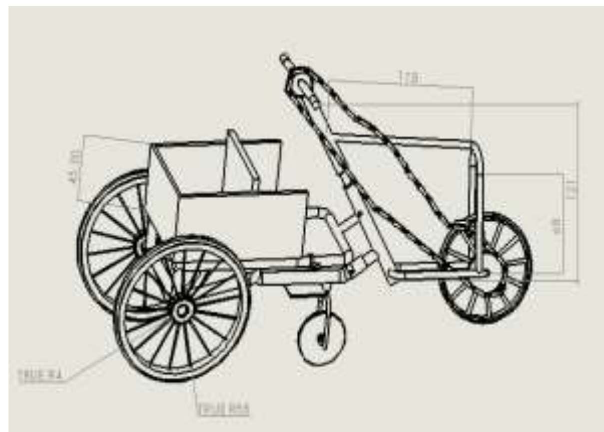

Figure 5: Isometric view of the wheel chair

NOMENCLATURE

Ø Diameter (mm)

E Modulus of Elasticity (Mpa)

y Deflection (mm)

M_{LOAD} Weight of the load (N)

$M_{TRICYCLE}$ Weight of the tricycle acting at the centre of gravity (N)

SF Shear force (N)

BM Bending Moment (Nmm)

I Moment of Inertia (mm^4)
π Pie
n Factor of Safety
σ_{max} Maximum stress (Mpa)
R_A Reaction Force at point A (N)
R_B Reaction Force at point B (N)
ε Strain

Table 4: Cost Analysis of the tricycle wheel chair

S/N	DESCRIPTION OF ITEM	QTY	UNIT COST (NGN)	COST (NGN)
1	Back Wheels Size 24	2	2,250	4,500
2	Back Tyres Size 24	2	1,000	2,000
3	Back Tubes Size 24	2	350	700
4	Front Tyre Size $20 \times 20 \times {}^{3}/_{4}$	1	-	800
5	Front Tube Size $20 \times 20 \times {}^{3}/_{4}$	1	-	400
6	Front Wheel Size $20 \times 20 \times {}^{3}/_{4}$	1	-	2,200
7	Set of Pedal	1	-	500
8	Set of Bicycle Crank		-	800
9	Free Wheel Chain	2	400	800
10	Long John Fork (High Jark)	1	-	800
11	Gear Free Wheel	1	-	500
12	Set of Gear	1	-	1000
13	Elbows for small & large size of galvanized steel pipes ($\emptyset 2mm$&thickness of 2.5mm)	18	400	7,200
14	Full length of galvanized steel pipe	3	1,800	5,400
15	Engine compartment (bicycle hub)	-		1,500
16	Electrode gauge 12	1 pkt	-	1,500
17	Castor wheel	1		2,000
18	Set of Ring bearings	1		400
19	Transportation			4,000
20	Labor			20,000
	Total	**#56,700**		