Journal of Engineering and Development, Vol. 14, No. 4, December (2010) **ISSN 1813-7822**

Design And Manufacturing Of A New Prosthetic Low Cost Pylon For Amputee

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Abstract

The Standard prosthetic pylon is manufacturing from aluminum -titanium alloys as a result of light weight. In this study, a three prosthetic pylon are design and manufactured from different layers composite materials (6 layers ,9 layers and 12 layers).

The mechanical properties such as σy and σ_{ult} and σ_e were measured for all type of pylon , Also , design pylon fatigue tester and impact pylon test then all pylon were tested by these device .

All types of new prosthetic pylons are light and cheap comparing with the standard pylon Therefore, to choose the best pylon , the weighted method is preferred, this method depend on practical experience. From this method the optimum choice pylon (kp) , it explains that the Pylon II is good .

Keyword : Pylon , amputee ,fatigue , impact ,optimum .

الخلاصة

ان الساق الصناعي القياس يصنع من سبيكة الالمنيوم تيتانيوم و هو خفيف الوزن الى حد ما . في هذه الدراسة تم تصميم ثلاث انواع من السيقان الصناعية من مواد متراكبة من طبقات مختلفة لمادة البرلون (6 طبقات ,9 طبقات و 12 طبقة)وتم قياس الخواص الميكانيكية كاجهاد الخضوع و اجهاد الشد الاقصى و حد الكلال لكل الانواع الثلاث. كما تم تصميم اجهزة خاصة منها جهاز قياس عمر الساق و جهاز قياس قابلية امتصاص الساق للصدمة وتم اختبار جميع الانواع بتلك الاجهزة .

كل الانواع المصنعة تميزت بخفة وزنها و رخصها و قابلية امتصاص جيدة مقارنة بالساق القياسية و لاختيار النوع الافضل من الانواع الثلاث فقد تم اختيار طريقة الامثلية Kp و كان النوع الثاني من السيقان هو الافضل و الذي يتكون من تسع طبقات .

1. Introduction:

There are various causes of amputation. Common causes are vascular disease, cancer, infection, trauma, and birth defects. Lower limb amputations may be performed at different levels along the lower limb. A transtibial or below-knee (B/K) amputation is an amputation performed through the shank (tibia), while a transfemoral or above-knee (A/K) amputation is an amputation performed through the thigh (femur). Other levels of amputation include partial foot amputations and amputations through the ankle, knee or hip joints.[1]

In Iraq, the Young's and elders represent the largest percentage of individuals with a below knee amputation (BK) due to landmines or disease of the limb.

BK prostheses are typically comprised of four major components these are: Socket, pylon, prosthetic foot and couplings.

The pylon is manufacturing from aluminum -titanium alloys as a result of light weight, In this study , it was focus on the pylon design.There are some researcher in this field such as N. Bern, et al, [2] used a shorter pylon transducer for measurement of prosthetic forces and moment during amputee gait.

Ian Brown and Ross Stewart [3] investigated the problem by using FEM analysis which were crack growth analysis are used to build a model of the expected life of the pylon.

Glenn K. Klute, et al [4] studied the mechanical properties of VSAP vertical shock absorbing pylons to standardized loading conditions to evaluate the effect of VSAP on amputee gait. K. L. COLEMAN, et al [5] explored the effects of trans-tibial prosthesis pylon flexibility on ground reaction forces (GRFs) associated with walking and step down.

2. Modeling Human Walking And Mathematical Analysis Of The Pylon:

The ultimate aim of biomechanical analysis is to find out what the muscles are doing: The timing of their contraction, the amount of force generated.The approaches to the modeling and analysis of human gait can be divided into two classes analytical models and analyses, and statistical methods.

The computational method is used to evaluate an alternative center of mass , ankle moment and dorsi-flexion angle from the free body diagram of lower limb "above ankle joint" by assuming the body as straight line and joint at knee and hip, Figure(1). When the equilibrium equation is applied, the equations of motion in X and Y directions may be obtained as follows:

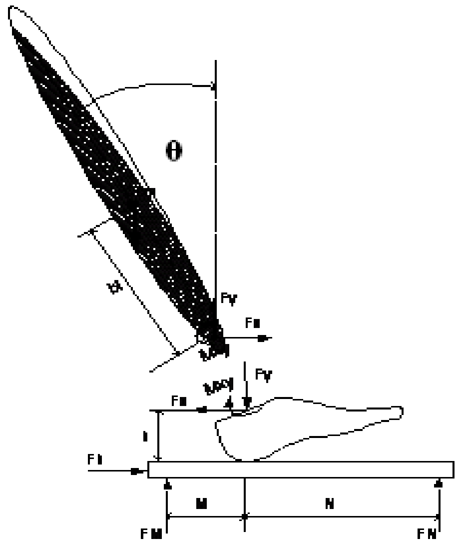


Figure (1) Force Distributed With Ground reaction force (GRF)

$$F_x = M_t \ddot{x}_c \qquad \text{.... (1)}$$

$$F_y = M_t (g + \ddot{y}_C) \qquad \text{.... (2)}$$

The angle of inclined with vertical axes is :

$$\theta = 2\tan\left(\frac{-K_1 \mp \sqrt{(K_1{}^2 + K_2{}^2 - K_3{}^2)}}{(K_3 - K_2)}\right) \qquad \text{....(3)}$$

The location of the COM can be obtained as

$$y_C = b_i Cos\theta \qquad \text{....(4)}$$

$$x_C = b_i Sin\theta$$

The ankle moment can be evaluated with equation (5)

$$M_{XY} = F_N N - F_M M + F_h h - mga \qquad \text{...(5)}$$

Where :

$$K_1 = ((M_t + m)I - M_t{}^2 b_i{}^2)g - I(F_N + F_M) \qquad \text{...(6)}$$

$$K_2 = F_h I$$

$$K_3 = M_t b_i (F_N N - F_M M + F_h h)$$

F_N and F_M are ground reaction force perpendicular to the force plate, measured with front and rear transducers, respectively;

F_h is the ground reaction force parallel to the force plate measured with a transducer at the horizontal.

3.Stresses On The Suggested New Design Pylon:

There are numerous prosthetic Pylon designs available. These prosthetics pylons serve basic functions which include: support the body against gravity during standing and walking; absorb shock during gait cycle, preventing the fatigue failure, the new design takes in consideration the need for a lighter pylon for the elderly amputee population and its relative low cost.

The material chosen for the new design pylon was a composite materials . The ground reaction forces are applied vertical and horizontal .They cause moment at the ankle and forces. At heel strike there are two stresses are generated in the pylon end, bending stress and compression stress. At mid stance Phase the compression stress only, and at toe off phase, also there are two stresses (compression and bending).

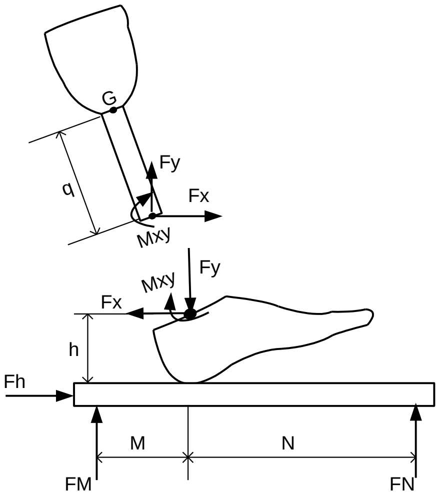


Figure (2) Forces and moment on the prosthetic below knee

$$\sigma_G = \frac{\mp Fy \cos\theta - Fx \sin\theta}{A} \mp \frac{[(Fy \sin\theta + Fx \cos\theta).q - Mxy](\frac{d_o}{2})}{I} \qquad \ldots(7)$$

In variable-amplitude loading, only those cycles exceeding some peak threshold will contribute to fatigue cracking.

At swing phase the:

$$\sigma_G = \sigma_{\min} = 0$$

At Stance phase (heel strike):

$$\sigma_G = \sigma_{Max} = \frac{Fy\cos\theta - Fx\sin\theta}{\frac{\pi(do^2 - di^2)}{4}} + \frac{[(Fy\sin\theta + Fx\cos\theta).q - Mxy](\frac{d_o}{2})}{\frac{\pi(do^4 - di^4)}{64}} \quad ..(8)$$

4. Finite Element Analysis:

Various phenomena treated in science and engineering are often described in terms of differential equations formulated by using their continuum mechanics models. The geometry of pylon was drawn by create modeling (volume, hallow cylinder), all dimensions is fixed then save this a file as IGES extension in order to open and modify by ANSYS WORKBENCH program[6]. In this program ,the pylon geometry can be meshed as in figure (3) , then the fatigue was chosen from analysis type , the boundary condition is fixed then the material properties which is limited with S-N curve . In this search, the three S-N curve for three different pylon were entered , the soderberge theory was applied .The minimum safety factor was calculated for each pylon , also the stress distribution was calculated .

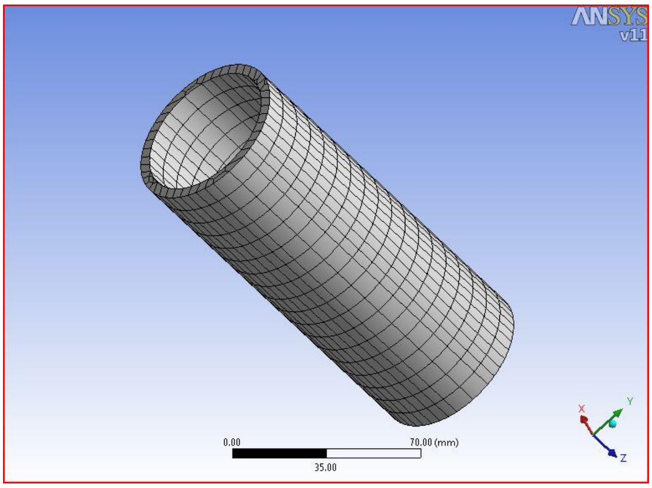


Figure (3) Modeling of pylon by ANSYS program

5. Experimental Work :

The theoretical and experimental calculations depend on the mechanical properties of the material; these can be found from the tensile test of standard specimens according to the recommendation of ASTM D-638[7].

The specimens used in this investigation are classified as:

Group (I) for Materials of pylon (I) has 12 layers of perlon : 12 Specimens .

Group (II) Materials of pylon (II) has 9 layers of perlon: 12 Specimens .

Group (III) Materials of pylon (III) has 6 layers of perlon: 12 Specimens .

The endurance limit and S-N curve are powerful techniques for the theoretical and numerical analysis. The S-N curve is used in the numerical model of the new pylon design.

The specimens were manufactured by casting and preparation according to the machine manual; all specimens are made from composite materials and the test is performed by HI-TECH device[8].

5.1 Design and Manufacturing The Fatigue Pylon Tester:

The fatigue foot, pylon tester, Figure (4), have been designed and built using the functional requirements outlined in ISO standards[9].

According to ISO 10328 standards, The fatigue tester has been designed to simulate human gait by alternating the heel and toe loadings.

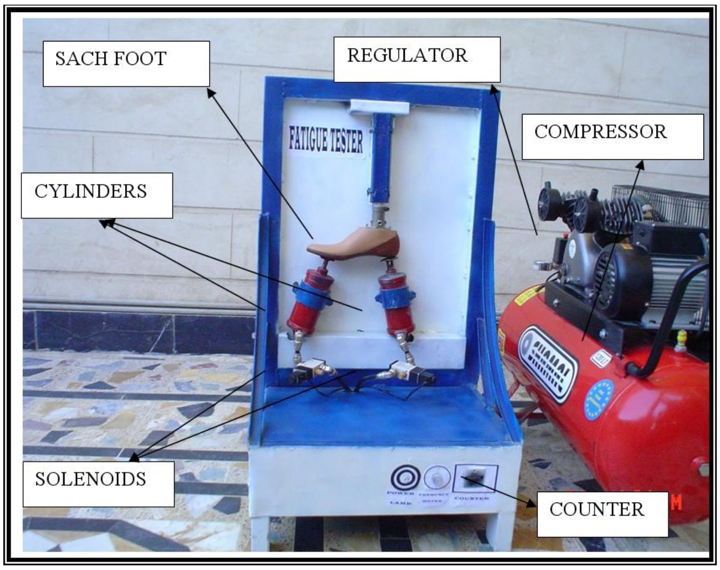


Figure (4) Fatigue Pylon Tester

5.2 Design and Manufacturing The Impact Pylon Tester:

The properties of the prosthetic components prescribed to amputees have the potential of comfort, mobility, and health. The impact pylon tester, Figure (5) has been designed and built with indicator.

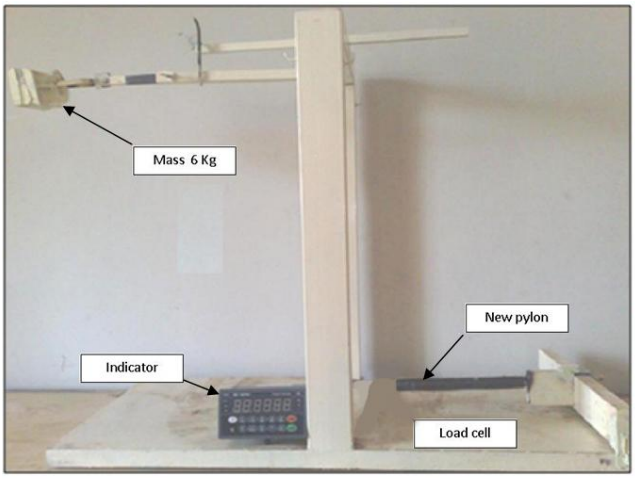


Figure (5) Impact Pylon Tester

6. Results and Discussion :

For gait analysis, the moment of interface region between socket and pylon has been calculated. The three new pylons have been designed from composite material and the life of new pylons (number of cycles) and transverse force were measured by pylon fatigue tester and impact pylon tester respectively. Figures (6) display the inclined angle, the angle is increased with gait cycle, from this result the moment at interface region between socket and pylon is obtained as shown in figure (7) .

The moment is increased at heel strike phase then it is equal to zero at mid stance then it is increased at the opposite direction at toe off , this behavior is due to change in ground reaction value and angle of inclination with gait cycle. This occurs because the prosthetics foot does not produce the controlled plantar flexion obtained naturally by eccentric contraction of the dorsiflexion. In this study , weight acceptance and push off floor reaction forces are evaluated from motion .

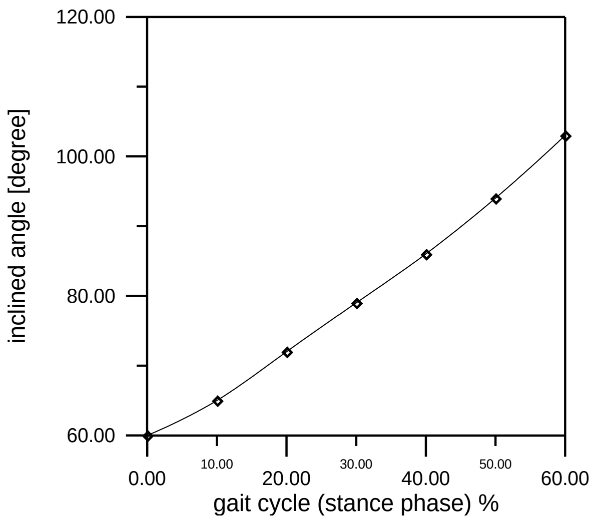


Figure (6) Inclined Angle With Gait Cycle

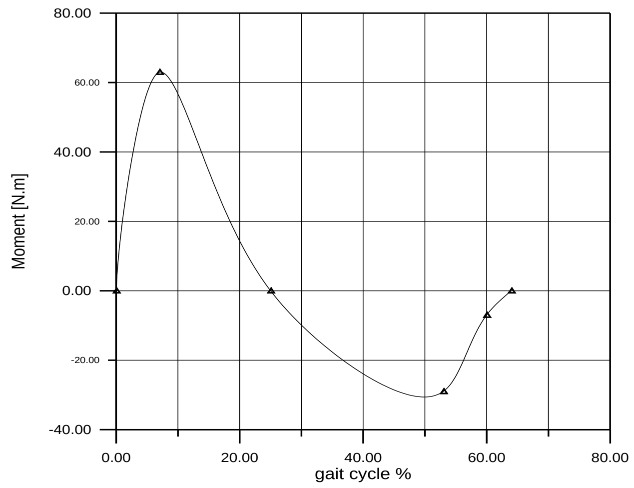
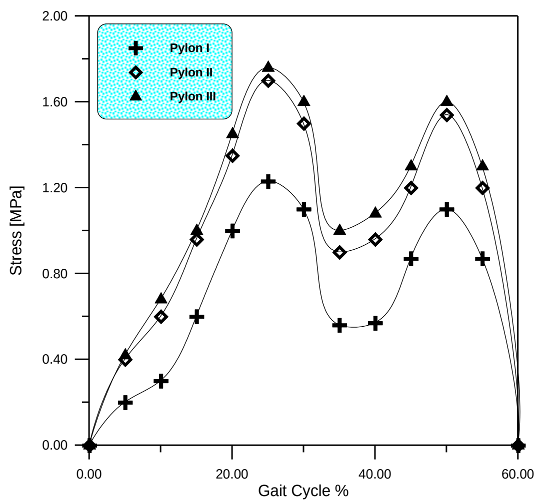


Figure (7) Moment At Interface Region With Gait

6.1 Numerical Results:

The stress distribution for all types of pylon with gait cycle has been calculated. Also the safety factors of prostheses pylons have been calculated based on Soderberg by ANSYS program. Figure (8) shows the stress distribution with gait cycle for all types of pylon .The stress is maximum at heel strike then decreasing at midstance then increasing again. This alternative value of stress is due to the change of ground reaction force . The stress distribution with phase is such as heel strike , mid stance and toe off by four axis .A axis , P axis and M axis , are showing the Von Mises stress distribution in the Pylon overloading conditions (phase) .

The Safety Factors for Pylon I are greater than Pylon II and Pylon II (Figure(9)), this is due to the cross sectional area and mechanical properties of pylon I are greater than Pylon II and Pylon III .



Figure(8) Stress Distribution Three Pylon Type With Gait Cycle

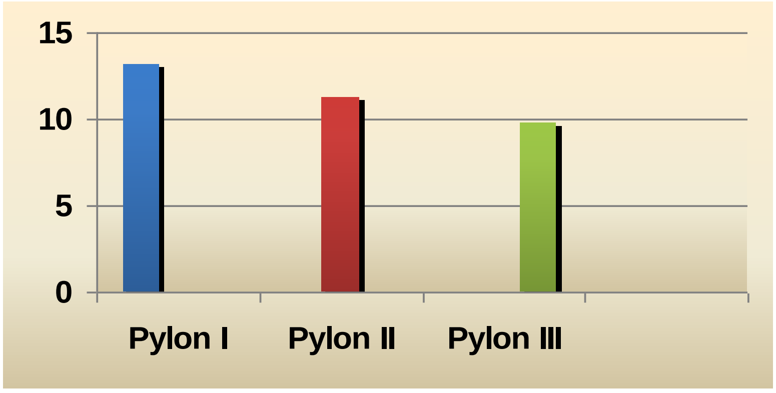


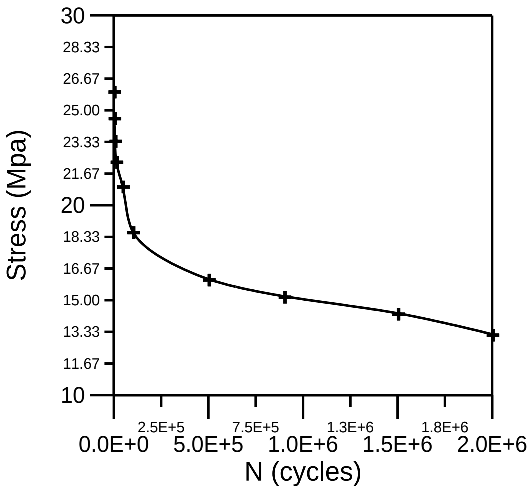
Figure (9) Minimum Safety Factor For Three Pylon Type

6.2 Exp

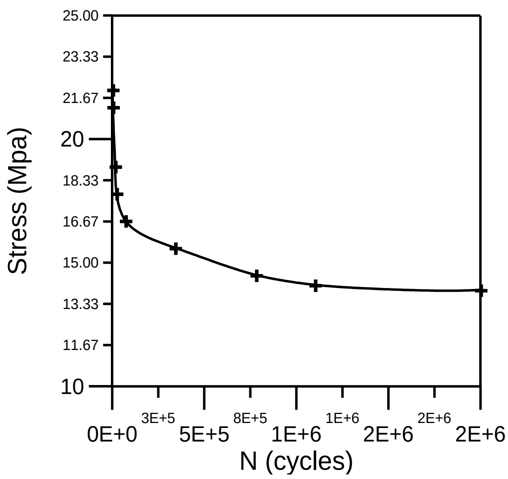
The ɔwn in Table (1)

Composite Material (12 Layers)	***27.3***	***48.2***
Composite Material (9 Layers)	***26.2***	***34.5***
Composite Material (6 Layers)	***16.5***	***25.7***

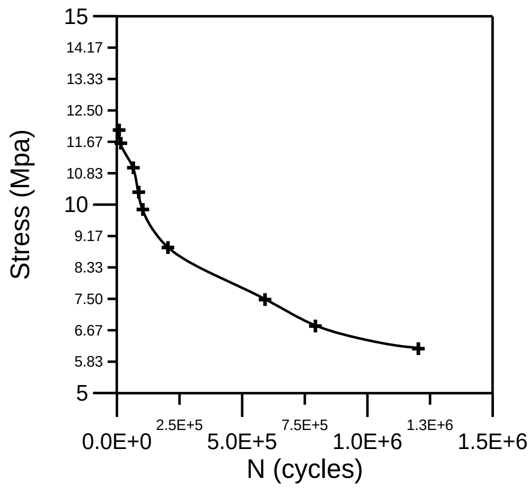
Figure (10-a) to figure (10-c) explain S-N curve for three materials type , the pylon I has a greater endurance limit than the other two types of pylon because it has a tensile strength greater than them.



Figure(10-b)



Figure(10-b)



Figure(10-c)

Figure(10) A,B And C. S-N Curve For: Pylon I , Pylon II And Pylon III Materials

6.3 Fatigue Pylon Tester Results:

In order to determine the validity of the new pylon fatigue tester in comparison to other tester currently being used, the industry standard SACH foot was tested with the new pylon , SACH foot has a failure at 912321 but the pylon III has no failure. The pylon III was tested only because it has smaller tensile strength than other pylons .

Upon initial cycle testing in the fatigue tester, the fatigue failure of the SACH foot was not detected until failure, since crack propagation from a location is difficult to be observed visually.

6.4 Impact For Different Type Of Pylon :

The impact response at heel strike reveals that the pylon has the largest peak force, followed in order by pylon I , Pylon II and Pylon III . In general, large peak forces have been coupled with small deformations across different velocities. From the force transverse in four pylon , pylon I has a good absorbing energy because the force transfers in this pylon has the smallest value with respect to all types of pylon . Also ,the standard pylon has less absorbed energy as shows in Table (2) .This result is due to different materials which pylon manufactured . Pylon I, Pylon II and Pylon III are manufactured from composite materials (fibers and polymer) . the polymer has a good absorbed energy than a metal (standard pylon).

These results indicate that the standard pylon is stiffer and dissipates less impact energy than the new pylon . The materials of new pylon is less stiff and dissipates more energy and might be considered analogous to walking , therefore the force transmitted is decreased when the new pylon is used .

Table (2) Pylons with transverse force

Pylon type	Force transfer (Kgf)	Reduction %
Standard Pylon	17	……………
Pylon I	11.5	32
Pylon II	9	47
Pylon III	8	52

6.5 Cost and Weight Of Pylons:

All types of new prosthetic pylons are light comparing with the standard pylon because new pylons are manufactured from composite material ,this materials is lighter than metal pylon .Table(3) shows the weight reduction percentage for each pylon .

Also , new prosthetic pylons are economic with respect to the standard pylon . So table (3) explain the cost reduction percentage.

Table (3) Weight reduction and cost reduction percentage

Type of pylon	Weight percentage reduction %	Cost percentage reduction %
Pylon I	47	83
Pylon II	50.6	85.5
Pylon III	51.4	87

For all these results , the Pylon I has a good Safety factor and strength with respect to Pylon II and Pylon III but it has bad absorbing energy ,weight and cost with respect to Pylon II and Pylon III.

Therefore, to choose the best pylon , the weighted method are used, this method depend on practical experience:

Kp=(40%S.Fpercentage)i+(30%Impactreduction)i+(20%weight reduction)i+(10% cost reduction)

Kp= optimum choose pylon

Where i=pylon I, pylon II and pylon III.

$$S.F_{percentage} = \frac{safety\ \ factor\ Pylon_i}{safety\ \ factor\ Pylon\ \ I}$$

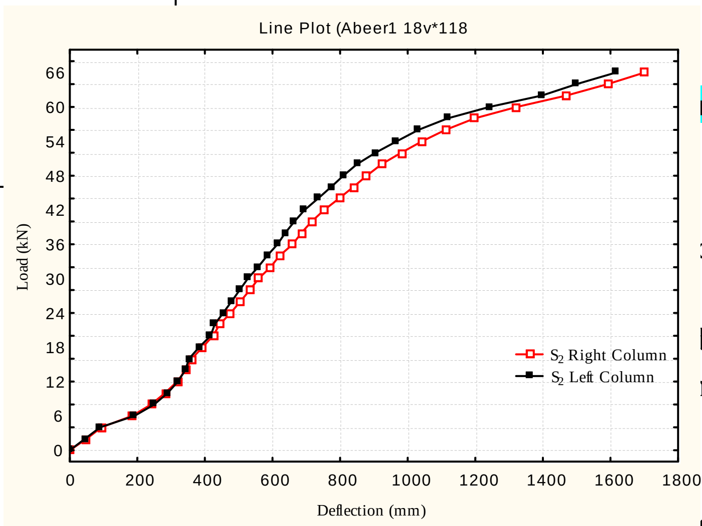
From this method Table (5-5) shows the optimum choice pylon (Kp) , it explains that the Pylon II is good .

Table (4) Type Of Pylons With Optimum Choose Factor (Kp)

Type of pylon	Optimum choice pylon (Kp)
Pylon I	63.3
Pylon II	66.4
Pylon III	64.18

7. Conclusions:

1. All type of new prosthetic pylon design are a good mechanical properties .
2. New prosthetic are a good absorb energy and lighter than standard prosthetic pylon .
3. New prosthetic pylons are economic with respect to the standard pylon .
4. Pylon has 9 layers is better than another pylon has 6 layer and 12 layer because the optimum chosen pylon factor (Kp) is higher than another pylon .



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